Verification Examples

AxisVM X5

2018

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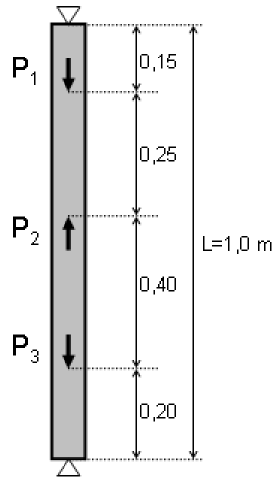
Linear static

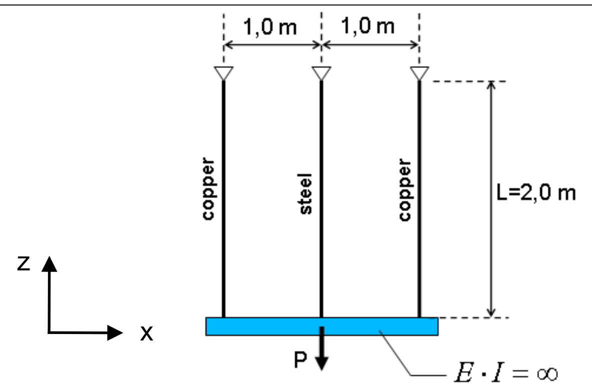
Software Release Number: X5r1
Date: 07. 11. 2018.
Tested by: InterCAD
File name: beam1.axs

Thema	Supported bar with concentrated loads.
Analysis Type	Linear analysis.
Geometry	 Side view Section Area = 100,0 cm^2 (10×10)
Loads	Axial direction forces P_1 = -200 kN, P_2 = 100 kN, P_3 = -40 kN
Boundary Conditions	Fix ends, at R_1 and R_5.
Material Properties	E = 20000 kN / cm^2 ν = 0,3
Element types	Beam element
Mesh	
Target	R_1 , R_5 support forces
Results	

	Theory	AxisVM	%
R_1 [kN]	-22,00	-22,00	0,00
R_5 [kN]	118,00	118,00	0,00

Software Release Number: X5r1
Date: 07. 11. 2018.
Tested by: InterCAD
File name: beam2.axs

<table>
<tr><td>Thema</td><td>Thermally loaded bar structure.</td></tr>
<tr><td>Analysis Type</td><td>Linear analysis.</td></tr>
<tr><td>Geometry</td><td>



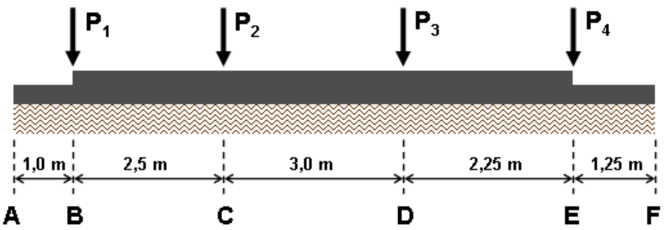
Side view

Sections:
Steel: $A_S = \pi \times 10^{-4}$ m² (D=2cm)
Copper: $A_C = \pi \times 10^{-4}$ m² (D=2cm)</td></tr>
<tr><td>Loads</td><td>P = -12 kN (Point load)
Temperature rise of 10 °C in the structure after assembly.</td></tr>
<tr><td>Boundary Conditions</td><td>The upper end of bars are fixed.
Nodal DOF: Frame X-Z plane</td></tr>
<tr><td>Material Properties</td><td>Steel: E_S = 20700 kN / cm², ν = 0,3 , $\alpha_S = 1{,}2 \times 10^{-5}$ °C^{-1}
Copper: E_C = 11040 kN / cm², ν = 0,3 , $\alpha_C = 1{,}7 \times 10^{-5}$ °C^{-1}</td></tr>
<tr><td>Element types</td><td>Beam element</td></tr>
<tr><td>Target</td><td>S_{max} in the three bars.</td></tr>
<tr><td>Results</td><td>

	Theory	AxisVM	%
Steel S_{max} [MPa]	23,824	23,848	0,10
Cooper S_{max} [MPa]	7,185	7,199	0,19

</td></tr>
</table>

Software Release Number: X5r1
Date: 07. 11. 2018.
Tested by: InterCAD
File name: beam3.axs

<table>
<tr><td>Thema</td><td>Continously supported beam with point loads.</td></tr>
<tr><td>Analysis Type</td><td>Linear analysis.</td></tr>
<tr><td>Geometry</td><td>


Side view
(Section width = 1,00 m, height$_1$ = 0,30 m, height$_2$ = 0,60 m)</td></tr>
<tr><td>Loads</td><td>P_1= -300 kN, P_2= -1250 kN, P_3= -800 kN, P_4= -450 kN</td></tr>
<tr><td>Boundary Conditions</td><td>Elastic supported.
From A to D is K_z = 25000 kN/m/m.
From D to F is K_z = 15000 kN/m/m.
Nodal DOF: Frame X-Z plane</td></tr>
<tr><td>Material Properties</td><td>E = 3000 kN/cm^2
ν = 0,3</td></tr>
<tr><td>Element types</td><td>Rib element: Three node beam element. Shear deformation is taken into account.</td></tr>
<tr><td>Target</td><td>e_z, M_y, V_z, R_z</td></tr>
<tr><td>Results

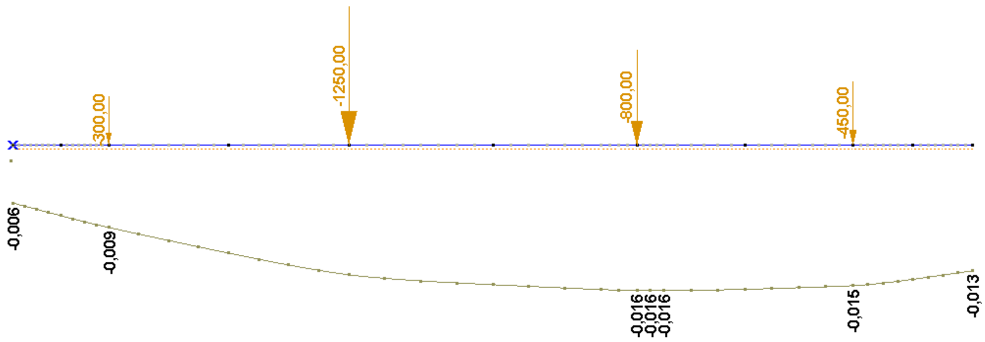
Results</td><td>


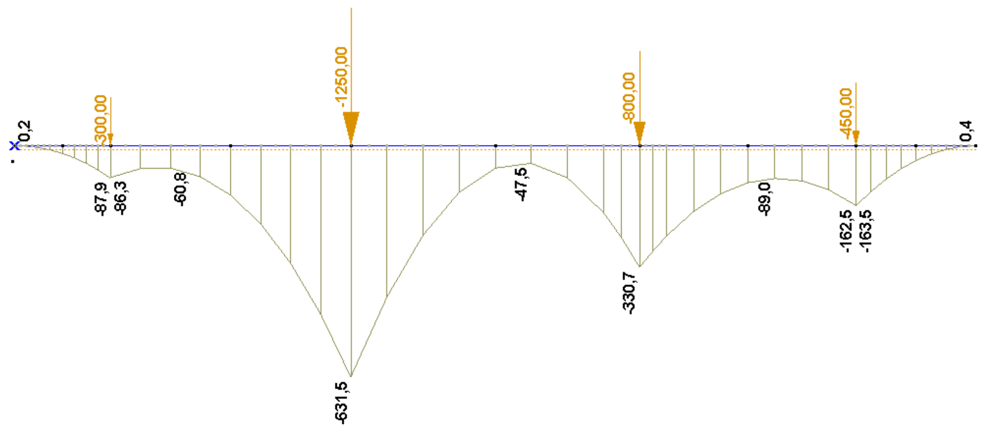
Diagram e_z


Diagram M_y</td></tr>
</table>

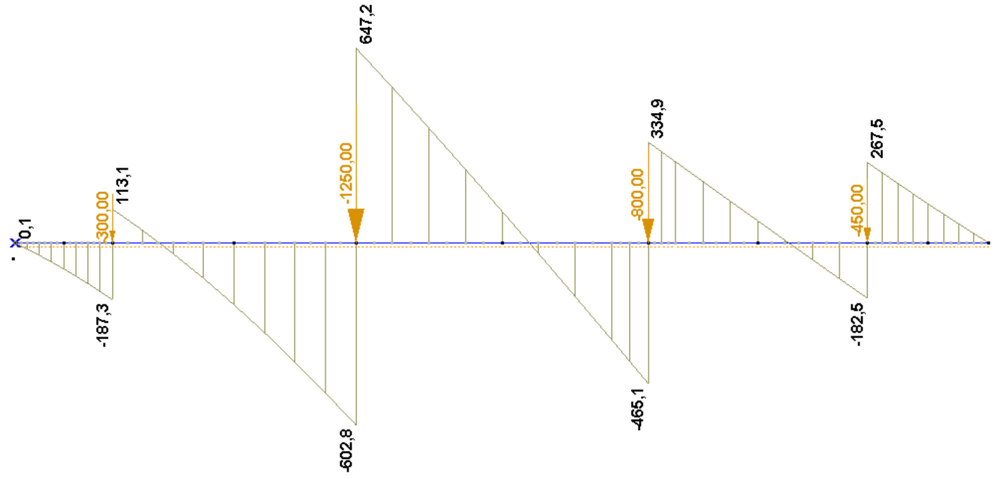


Diagram V_z

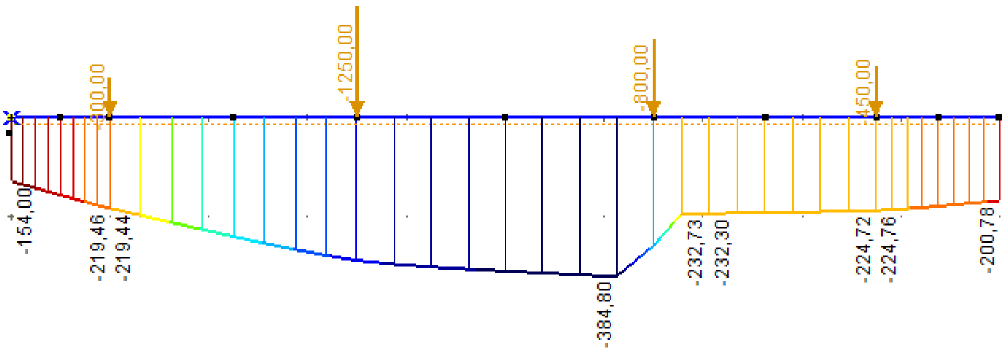


Diagram R_z

	Reference	AxisVM	e [%]
e_A [m]	0,0060	0,0062	3,33
e_B [m]	0,0090	0,0088	-2,22
e_C [m]	0,0140	0,0138	-1,43
e_D [m]	0,0150	0,0155	3,33
e_E [m]	0,0150	0,0150	0,00
e_F [m]	0,0130	0,0134	3,08

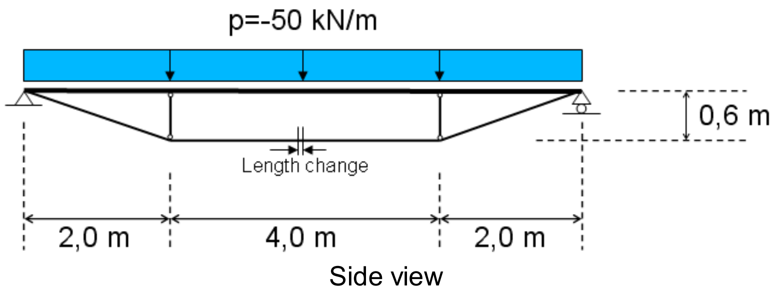
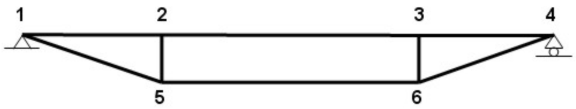
	Reference	AxisVM	e [%]
M_A [KNm]	0.0	0.2	0.00
M_B [KNm]	88.5	87.9	-0.68
M_C [KNm]	636.2	631.5	-0.74
M_D [KNm]	332.8	330.3	-0.75
M_E [KNm]	164.2	163.5	-0.43
M_F [KNm]	0.0	0.4	0.00

Results

	Reference	AxisVM	e [%]
V_A [KN]	0.00	0.09	0.00
V_B [KN]	112.10	113.09	0.88
V_C [KN]	646.80	647.15	0.05
V_D [KN]	335.00	334.86	-0.04
V_E [KN]	267.80	267.48	-0.12
V_F [KN]	0.00	-0.05	0.00

	Reference	AxisVM	e [%]
R_A [KN/m^2]	145,7	154,0	5,70
R_B [KN/m^2]	219,5	219,5	0,00
R_C [KN/m^2]	343,8	346,0	0,64
R_D [KN/m^2]	386,9	384,8	-0,54
R_E [KN/m^2]	224,5	224,7	0,09
R_F [KN/m^2]	201,2	200,8	-0,20

Software Release Number: X5r1
Date: 07. 11. 2018.
Tested by: InterCAD
File name: beam4.axs

Thema	External prestressed beam.
Analysis Type	Linear analysis.
Geometry	
Loads	p = -50 kN /m distributed load Length change = -6,52E-3 at beam 5-6
Boundary Conditions	eY = eZ = = 0 at node 1 eX = eY = eZ = 0 at node 4
Material Properties	E = 2,1E11 N / m^2 Beam 1-5, 5-6, 6-4 A = 4,5E-3 m^2 I_z= 0,2E-5 m^4 Truss 2-5, 3-6 A = 3,48E-3 m^2 I_z= 0,2E-5 m^4 Beam 1-4 A = 1,516E-2 m^2 I_z= 2,174E-4 m^4
Mesh	Beam 1-4: division into N segment: N = 12 
Element types	Rib element: Three node beam element, 1-5, 5-6, 6-4, 1-4 (shear deformation is taken into account) Truss element 2-5, 3-6
Target	N_X at beam 1-4 $M_{y,max}$ at beam 2-3 e_z at node 2

Results

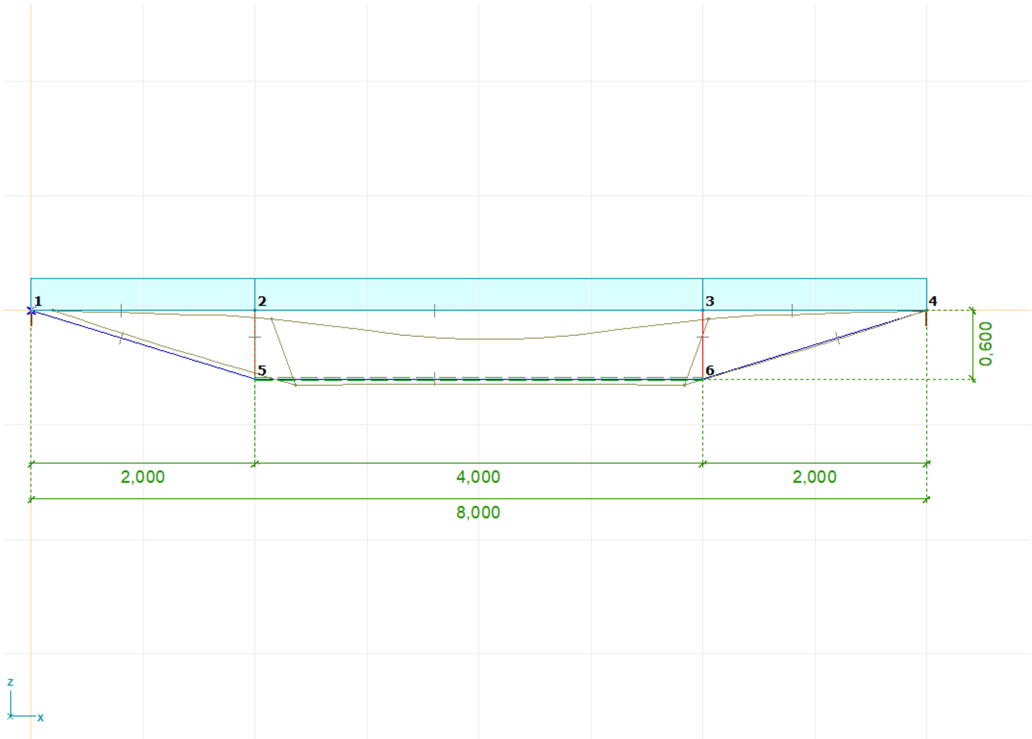
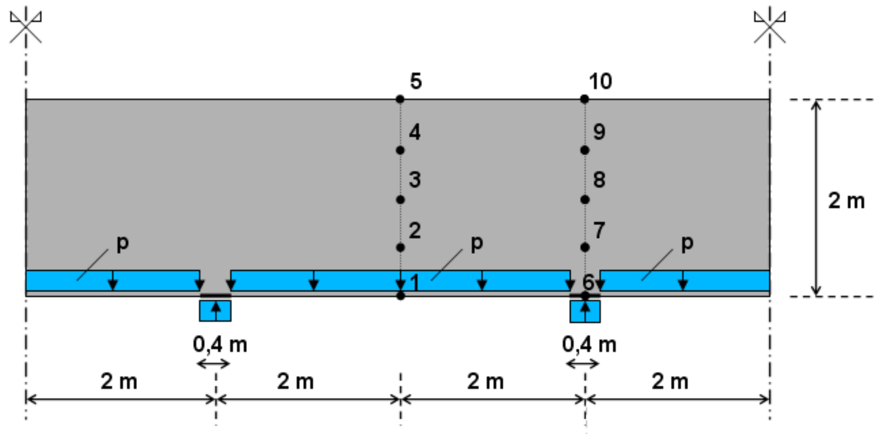
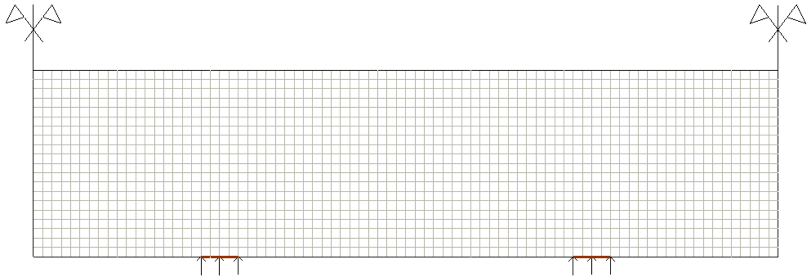


Diagram e_z

	ROBOT V6®	AxisVM	%
N_x [kN]	584,56	584,81	0,04
M_y [kNm]	49,26	34,20	-30,58
e_z [mm]	-0,5421	-0,5469	0,89

Software Release Number: X5r1
Date: 08. 11. 2018.
Tested by: InterCAD
File name: plane1.axs

Thema	Periodically supported infinite membrane wall with constant distributed load.
Analysis Type	Linear analysis.
Geometry	 Side view (thickness = 20,0 cm)
Loads	p = 200 kN / m
Boundary Conditions	vertical support at every 4,0 m support length is 0,4 m (Rz = 1E+3) Symmetry edges – Nodal DOF: (C C f C C C)
Material Properties	E = 880 kN / cm^2 ν = 0,16
Element types	Parabolic quadrilateral membrane (plane stress)
Mesh	
Target	S_{xx} at 1-10 nodes (1-5 at middle, 6-10 at support)

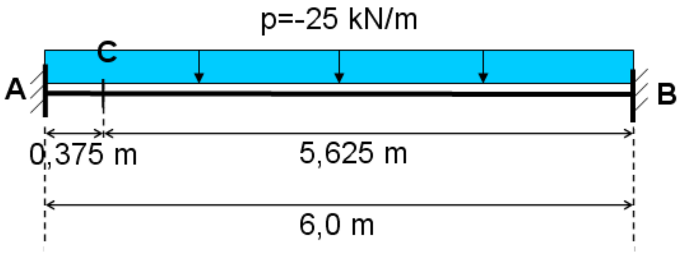
Results

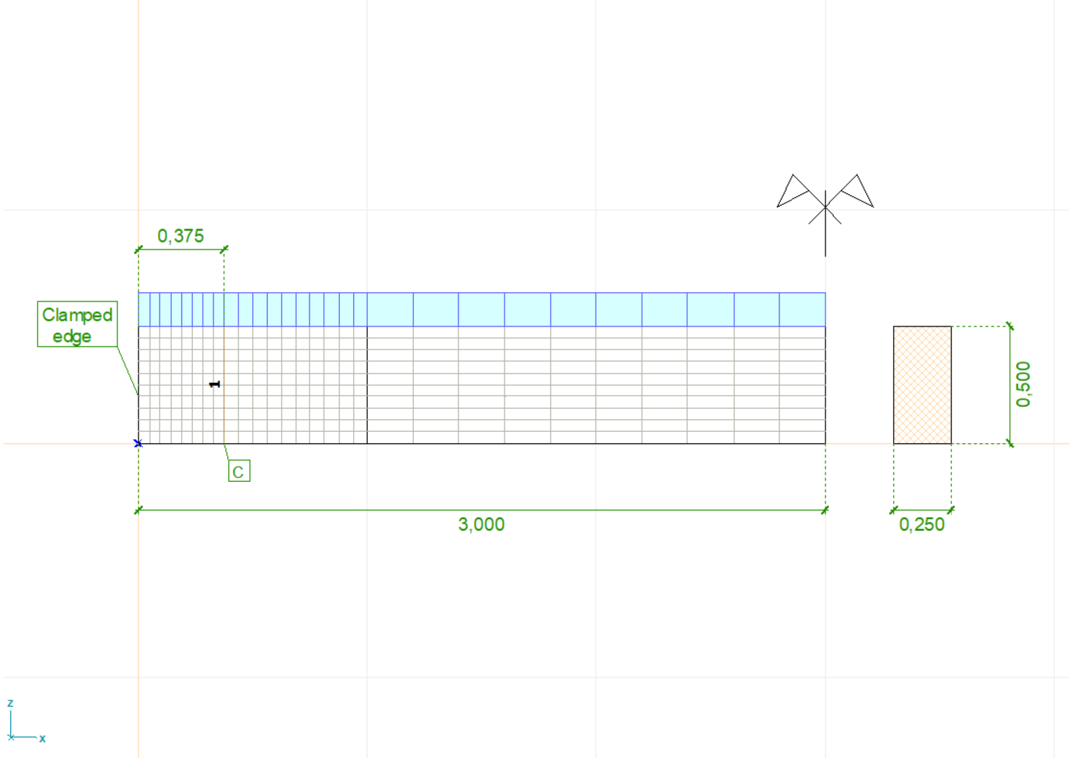
Node	Analytical [kN/cm^2]	AxisVM [kN/cm^2]	%
1	0,1313	0,1310	-0,23
2	0,0399	0,0395	-1,00
3	-0,0093	-0,0095	2,15
4	-0,0412	-0,0413	0,24
5	-0,1073	-0,1070	-0,28
6	-0,9317	-0,9166	-1,62
7	0,0401	0,0426	6,23
8	0,0465	0,0469	0,86
9	0,0538	0,0537	-0,19
10	0,1249	0,1245	-0,32

Reference:

Dr. Bölcskey Elemér – Dr. Orosz Árpád:
Vasbeton szerkezetek Faltartók, Lemezek, Tárolók

Software Release Number: X5r1
Date: 07. 11. 2018.
Tested by: InterCAD
File name: plane2.axs

<table>
<tr><td>Thema</td><td>Clamped beam examination with plane stress elements.</td></tr>
<tr><td>Analysis Type</td><td>Linear analysis.</td></tr>
<tr><td>Geometry</td><td>


Side view
</td></tr>
<tr><td>Loads</td><td>p = -25 kN/m</td></tr>
<tr><td>Boundary Conditions</td><td>Both ends built-in. Line support component stiffness: 1E+10.
Symmetry edge – Nodal DOF: (C C f C C C)</td></tr>
<tr><td>Material Properties</td><td>E = 880 kN / cm^2
ν = 0</td></tr>
<tr><td>Element types</td><td>Parabolic quadrilateral membrane (plane stress)</td></tr>
<tr><td>Mesh</td><td>


Side view
</td></tr>
</table>

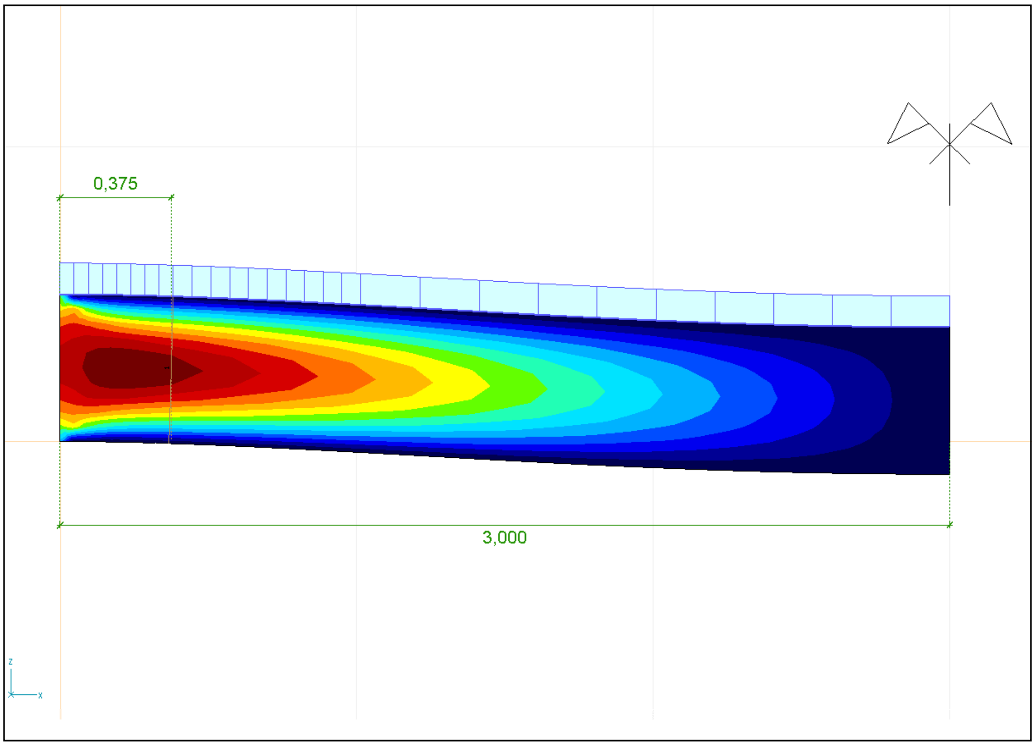
<table>
<tr><td>Target</td><td>$\tau_{xy,\ max}$ at section C</td></tr>
<tr><td>Results</td><td>


Diagram τ_{xy}

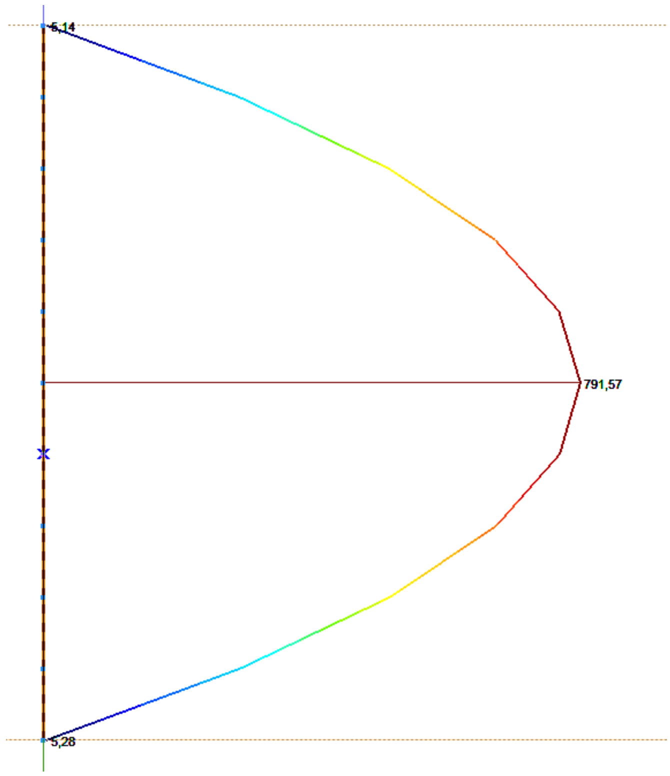
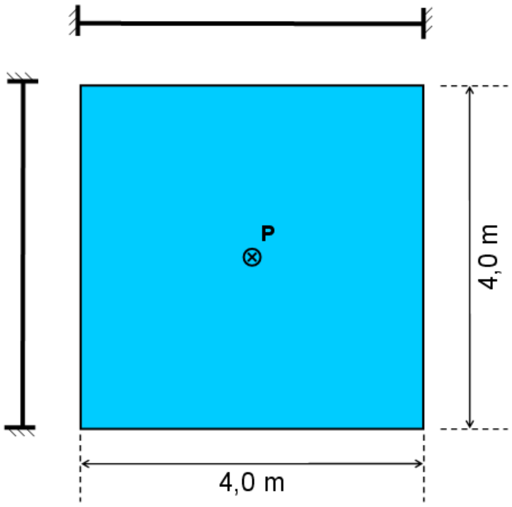
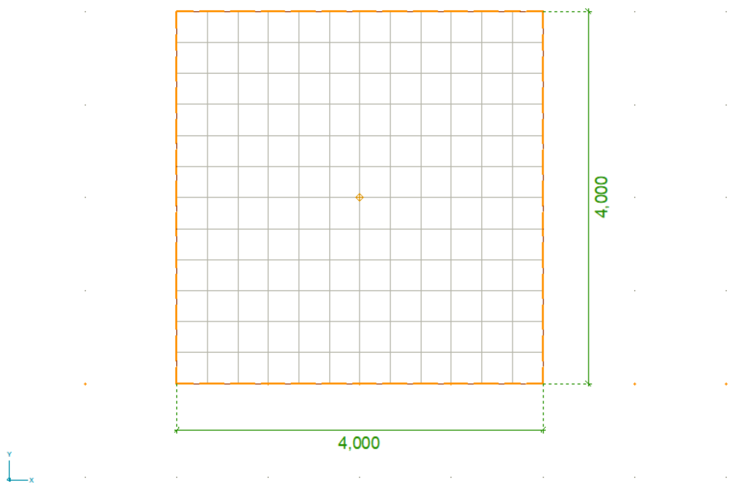


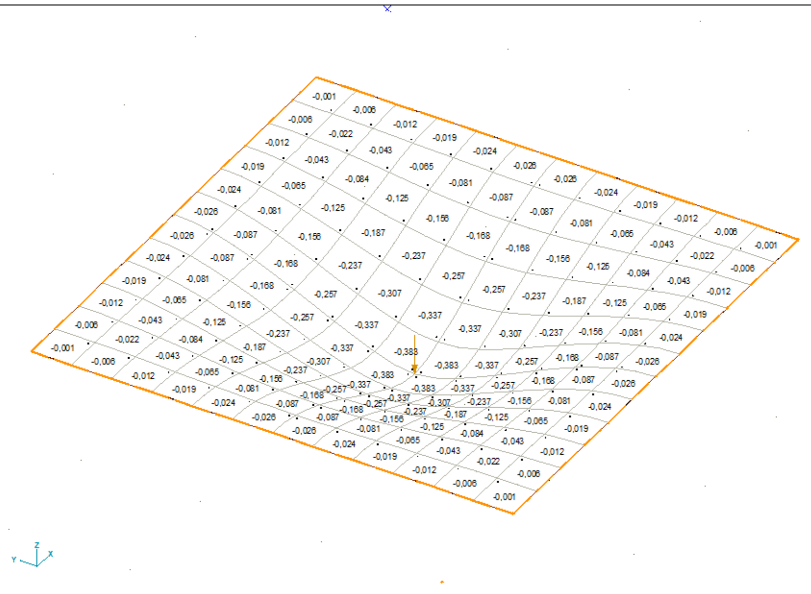
Diagram τ_{xy} at section C
</td></tr>
</table>

	$V = 65{,}625 \quad kN \quad (from \quad beam \quad theory)$ $S_y^{'} = 0{,}0078125 \quad m^3$ $b = 0{,}25 \quad m$ $I_y = 0{,}00260416 \quad m^4$ $\tau_{xy} = \frac{V \cdot S_y^{'}}{b \cdot I_y} = \frac{65{,}625 \cdot 0{,}0078125}{0{,}25 \cdot 0{,}00260416} = 787{,}5 \quad kN/m^2$ AxisVM result τ_{xy} = 791,57 kN / m^2 Difference = -0,10 % AxisVM result $V = \sum n_{xy} = 65{,}63 \quad kN$ Difference = 0,008 %

Software Release Number: X5r1
Date: 07. 11. 2018.
Tested by: InterCAD
File name: plate1.axs

Thema	Clamped thin square plate.
Analysis Type	Linear analysis.
Geometry	 Top view (thickness = 5,0 cm)
Loads	P = -10 kN (at the middle of the plate)
Boundary Conditions	eX = eY = eZ = fiX = fiY = fiZ = 0 along all edges Nodal DOF: Plate in X-Y plane
Material Properties	E = 20000 kN / cm^2 ν = 0,3
Element types	Plate element (Parabolic quadrilateral, heterosis type)
Mesh	
Target	Displacement of middle of the plate

Results



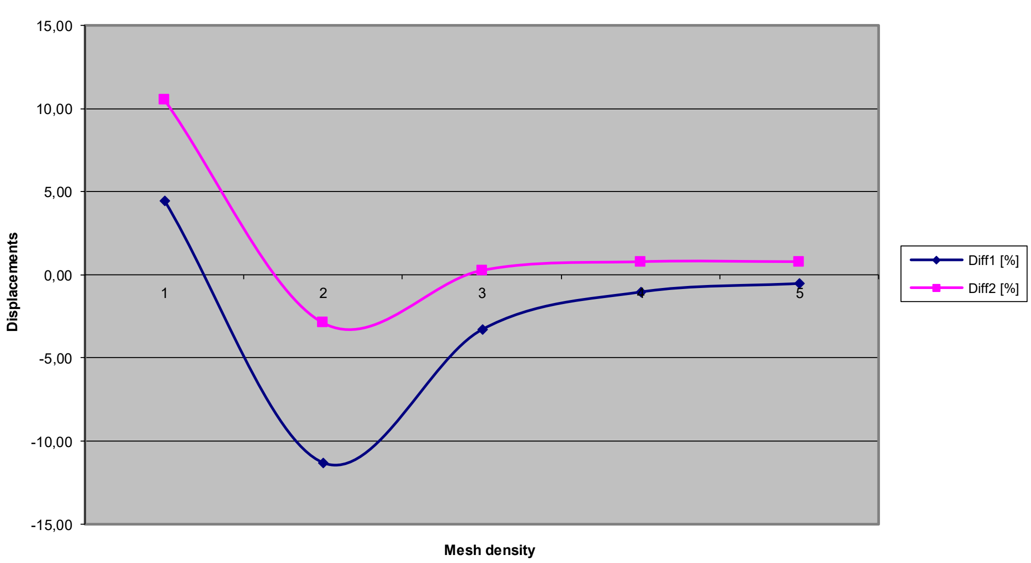
Displacements

Mode	Mesh	Book[1]	Timoshenko[2]	AxisVM	Diff[1] [%]	Diff[2] [%]
1	2x2	0,402		0,420	4,48	10,53
2	4x4	0,416		0,369	-11,30	-2,89
3	8x8	0,394	0,38	0,381	-3,30	0,26
4	12x12	0,387		0,383	-1,03	0,79
5	16x16	0,385		0,383	-0,52	0,79

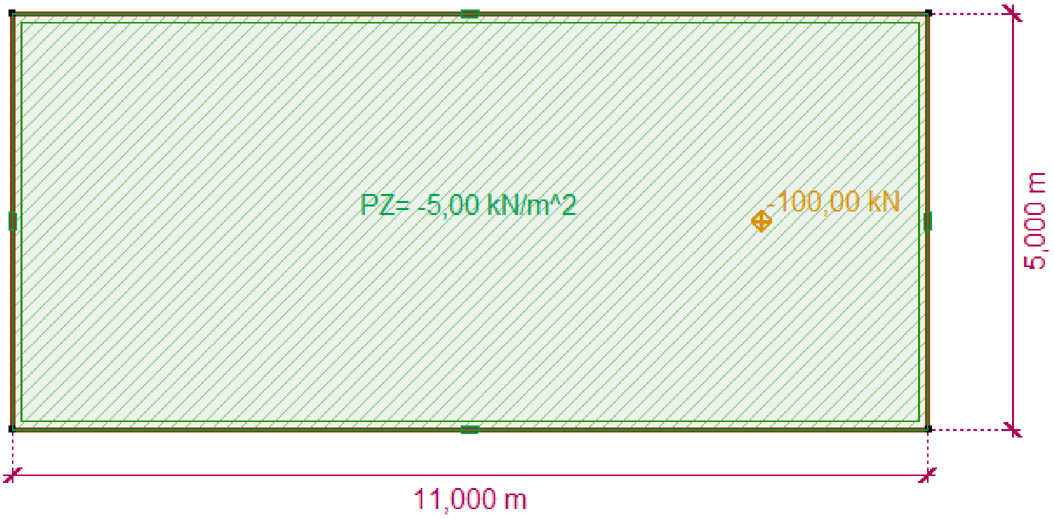
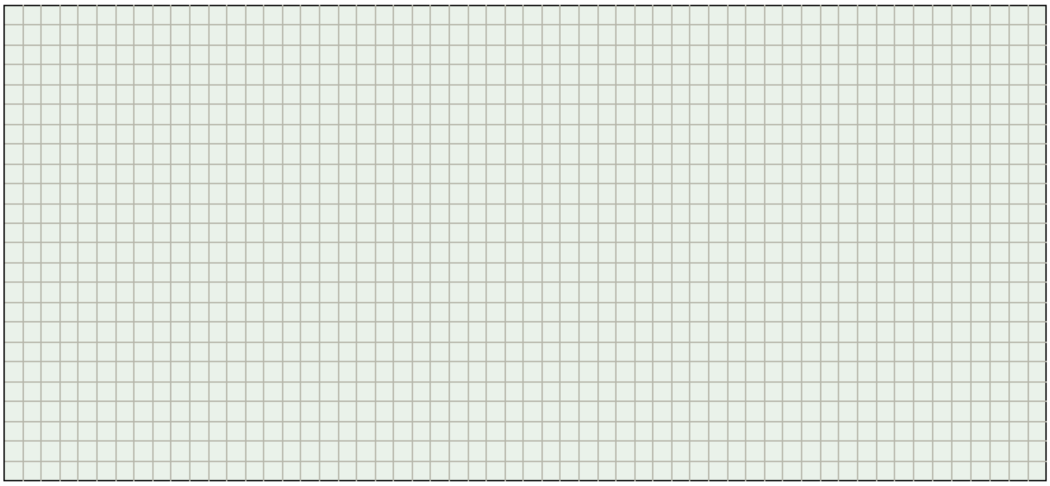
References:

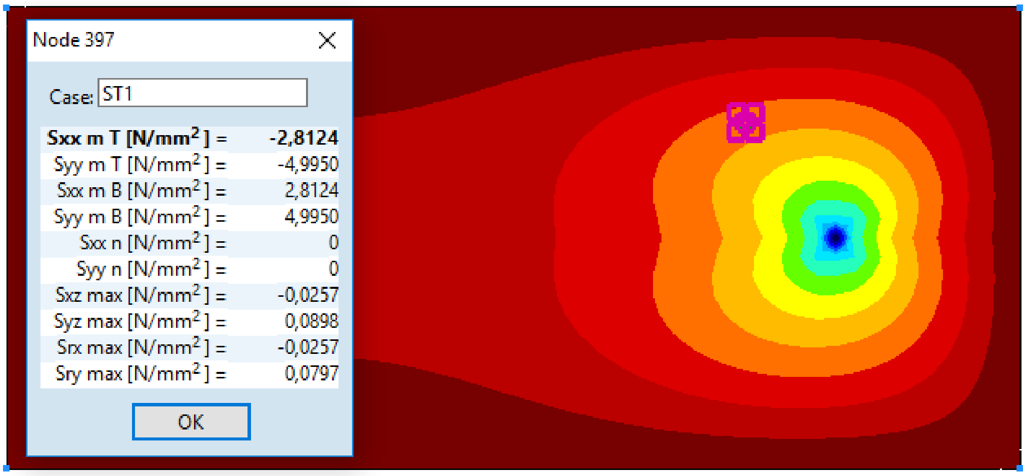
1.) The Finite Element Method (Fourth Edition) Volume 2.
/O.C. Zienkiewicz and R.L. Taylor/ McGraw-Hill Book Company 1991 London
2.) Result of analytical solution of Timoshenko

Convergency



Software Release Number: X5r1
Date: 08. 11. 2018.
Tested by: InterCAD
File name: XLAM_Example_1.axs

Thema	Simply supported XLAM plate.
Analysis Type	Linear analysis.
Geometry	 Top view (x-y plane)
Loads	P = -100 kN concentrated force acting at point (x = 9.0 m, y = 2.5 m) PZ = -5.00 kN/m^2 uniform load
Boundary Conditions	eX = eY = eZ = fiY = fiZ = 0, fiX = free along top and bottom edges eX = eY = eZ = fiX = fiZ = 0, fiY = free along left and right edges Nodal DOF at the remaining nodes: Plate in X-Y plane
Material Properties	Material quality equals to C24 timber.
Section Properties	MM 7s/240 XLAM section with “x” oriented top layer grain direction and Service Class 2, producing an overall thickness of 240 mm.
Element types	Plate element (Parabolic quadrilateral, heterosis type)
Mesh	 Average element length is 0.2 m.
Target	Displacement and stresses at node 397 (x = 8.022 m, y = 3.750 m), material stiffness matrix, shear correction factors.
	Displacements and stresses with Axis VM, ANSYS and from Navier solution[1]



x	y	Description	AxisVM	ANSYS	Diff [%]	Navier solution	Diff [%]
8.022 m	3.750 m	e_z [mm]	-18.024	-18.023	0.01	-18.024	0.00
8.022 m	3.750 m	σ_x maximum [N/mm^2]	2.812	2.805	0.28	2.812	0.02
8.022 m	3.750 m	σ_y maximum [N/mm^2]	4.995	4.951	0.89	4.982	0.26
8.022 m	3.750 m	τ_{xz} maximum [N/mm^2]	-0.0257	-0.0258	-0.23	-0.0256	0.27
8.022 m	3.750 m	τ_{yz} maximum [N/mm^2]	0.0898	0.0898	0.02	0.0897	0.11

Material stiffness matrix and shear correction factors from ANSYS[2]

```
SECTION Membrane & Bending(ABD) Matrix

0.179201E+07   17783.9       0.107657E-11    0.838190E-08  0.600267E-10 -0.908768E-27
 17783.9       940465.       0.510656E-10    0.600267E-10  0.426371E-08  0.103398E-24
0.107657E-11   0.510656E-10   61940.4       -0.908768E-27  0.103398E-24 -0.116415E-09

0.838190E-08   0.600267E-10 -0.908768E-27    0.105318E+11  0.853629E+08  0.272731E-08
0.600267E-10   0.426371E-08  0.103398E-24    0.853629E+08  0.258406E+10  0.129366E-06
-0.908768E-27  0.103398E-24 -0.116415E-09    0.272731E-08  0.129366E-06  0.297314E+09

SECTION Transverse Shear Correction Factors

0.250453       0.327087E-17

0.135442E-17   0.270064

SECTION Transverse Shear Stiffness (E)

 43358.3       0.113783E-11

0.113783E-11    24776.2
```

Material stiffness matrix and shear correction factos from Axis VM[3]

Membrane terms

(1792011,06943888, 17783,9274660452, 0)
(17783,9274660452, 940465,353384554, 0)
(0, 0, 61940,3931515536)

	Bending terms (10531,8234230298, 85,3628518370171, 0) (85,3628518370171, 2584,06340652272, 0) (0, 0, 297,313887127457) Shear terms[4] (10859,0681979786, 0) (0, 6691,718246181) Shear correction factors 0,250449727217332 0,270087010499269 [1] : with 50 harmonic terms included [2] : units in [N] and [mm] [3] : units in [kN] and [m] [4] : corrected shear stiffnesses

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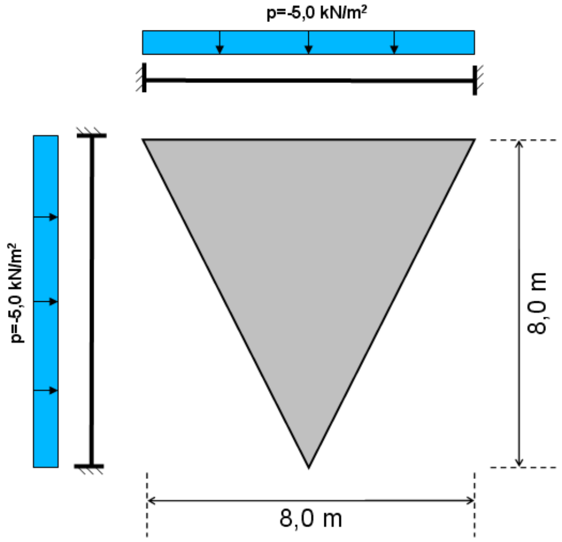
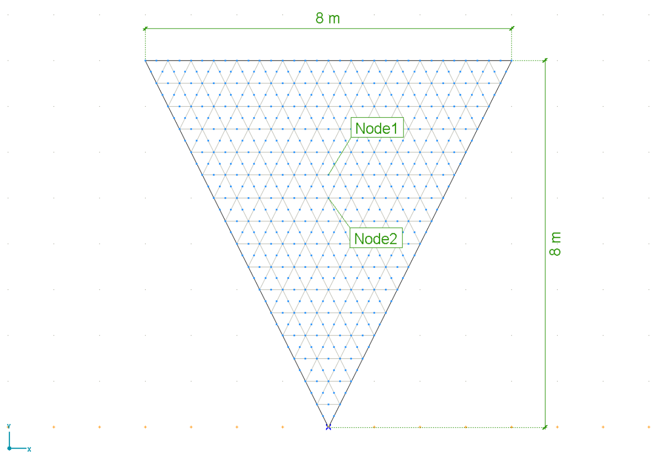
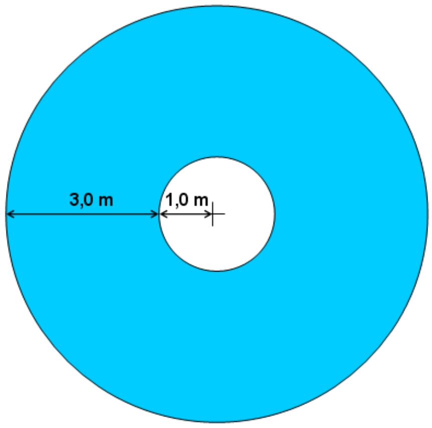
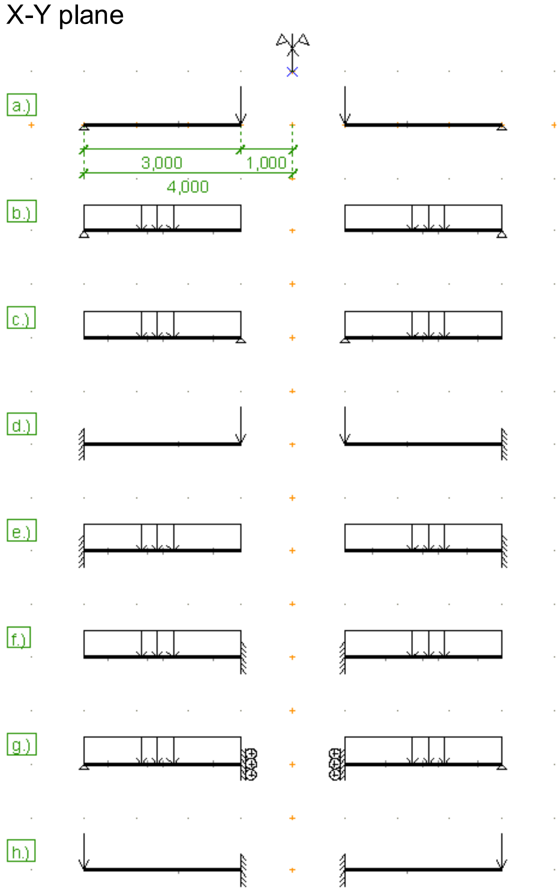
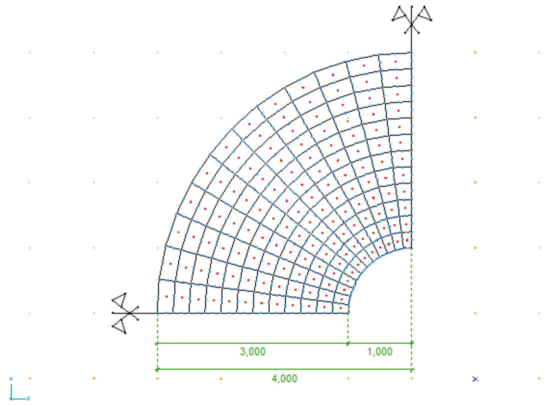
File name: plate2.axs

Thema	Plate with fixed support and constant distributed load.
Analysis Type	Linear analysis.
Geometry	 Top view (thickness = 15,0 cm)
Loads	P = -5 kN / m^2
Boundary Conditions	eX = eY = eZ = fiX = fiY = fiZ = 0 along all edges Nodal DOF: Plate in X-Y plane
Material Properties	E = 990 kN/cm^2 ν = 0,16
Element types	Parabolic triangle plate element
Mesh	
Target	Maximal eZ (found at Node1) and maximal m_x (found at Node2)
Results	

Component	Nastran®	AxisVM	%
eZ,max [mm]	-1,613	-1,595	-1,12
mx,max [kNm/m]	3,060	3,060	0,00

Software Release Number: X5r1
Date: 08. 11. 2018.
Tested by: InterCAD
File name: plate3.axs

Thema	Annular plate.
Analysis Type	Linear analysis.
Geometry	 Top view (thickness = 22,0 cm)
Loads	Edge load: Q = 100 kN / m Distributed load: q = 100 kN / m^2
Boundary Conditions	Nodal DOF: Plate in X-Y plane 
Material Properties	E = 880 kN / cm^2 ν = 0,3
Element types	Plate element (parabolic quadrilateral, heterosis type)

Mesh	
Target	S_{max}, e_{max}
Results	(tables below)

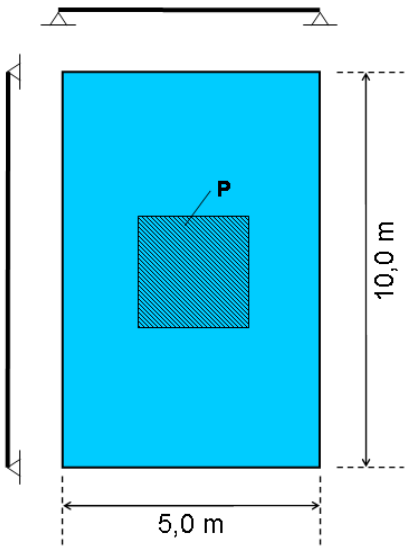
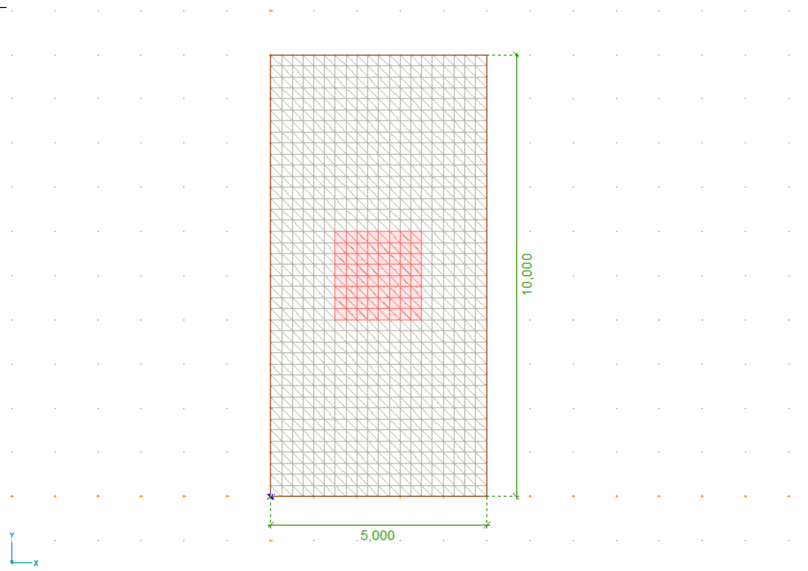
Model	Theory S_{max} [kN/cm2]	AxisVM S_{max} [kN/cm2]	%
a.)	2,82	2,78	-1,42
b.)	6,88	6,76	-1,74
c.)	14,22	14,10	-0,84
d.)	1,33	1,33	0,00
e.)	2,35	2,25	-4,26
f.)	9,88	9,88	0,00
g.)	4,79	4,76	-0,63
h.)	7,86	7,86	0,00

Model	Theory e_{max} [mm]	AxisVM e_{max} [mm]	%
a.)	77.68	76.16	-1.96
b.)	226.76	220.99	-2.54
c.)	355.17	352.89	-0.64
d.)	23.28	23.45	0.73
e.)	44.26	44.54	0.63
f.)	123.19	123.17	-0.02
g.)	112.14	111.94	-0.18
h.)	126.83	126.81	-0.02

Reference:

S. Timoshenko and S. Woinowsky-Krieger: Theory of Plates And Shells

Software Release Number: X5r1
Date: 07. 11. 2018.
Tested by: InterCAD
File name: plate4.axs

Thema	All edges simply supported plate with partial distributed load.
Analysis Type	Linear analysis.
Geometry	 Top view (thickness = 22,0 cm)
Loads	Distributed load: q = -10 kN / m^2 (middle of the plate at 2,0 x 2,0 m area)
Boundary Conditions	a.) eX = eY = eZ = 0 along all edges (soft support) b.) eX = eY = eZ = 0 along all edges φ = 0 perpendicular the edges (hard support) Nodal DOF: Plate in X-Y plane
Material Properties	E = 880 kN / cm^2 ν = 0,3
Element types	Plate element (Heterosis type)
Mesh	

<table>
<tr><td>Target</td><td>$m_{x, max}$, $m_{y, max}$</td></tr>
<tr><td>Results</td><td>

a.)

Moment	Theory	AxisVM	%
$m_{x, max}$ [kNm/m]	7,24	7,34	1,38
$m_{y, max}$ [kNm/m]	5,32	5,39	1,32

b.)

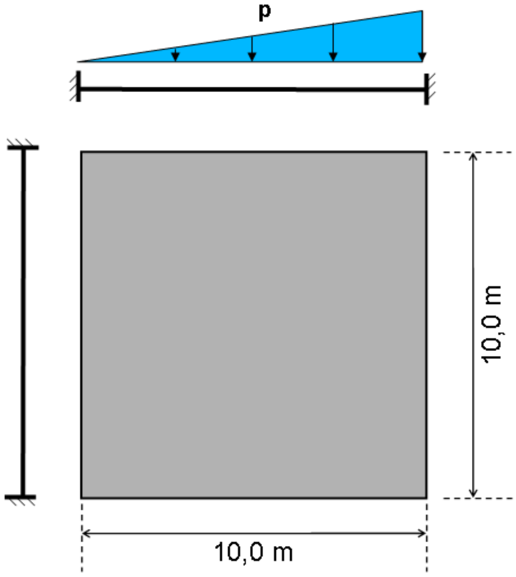
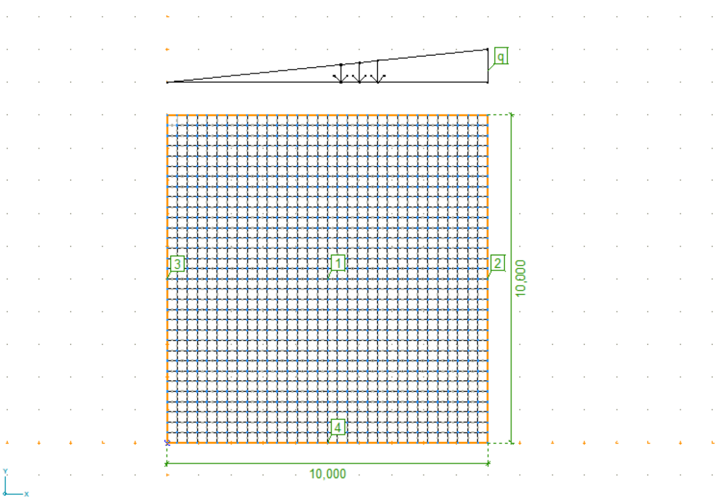
Moment	Theory	AxisVM	%
$m_{x, max}$ [kNm/m]	7,24	7,28	0,55
$m_{y, max}$ [kNm/m]	5,32	5,35	0,56

Reference:

S. Timoshenko and S. Woinowsky-Krieger: Theory of Plates And Shells

</td></tr>
</table>

Software Release Number: X5r1
Date: 07. 11. 2018.
Tested by: InterCAD
File name: plate5.axs

Thema	Clamped plate with linear distributed load.
Analysis Type	Linear analysis.
Geometry	 Top view (thickness = 22,0 cm)
Loads	Distributed load: q = -10 kN / m^2
Boundary Conditions	eX = eY = eZ = fiX = fiY= fiZ = 0 along all edges Nodal DOF: Plate in X-Y plane
Material Properties	E = 880 kN / cm^2 ν = 0,3
Element types	Plate element (Heterosis type)
Mesh	

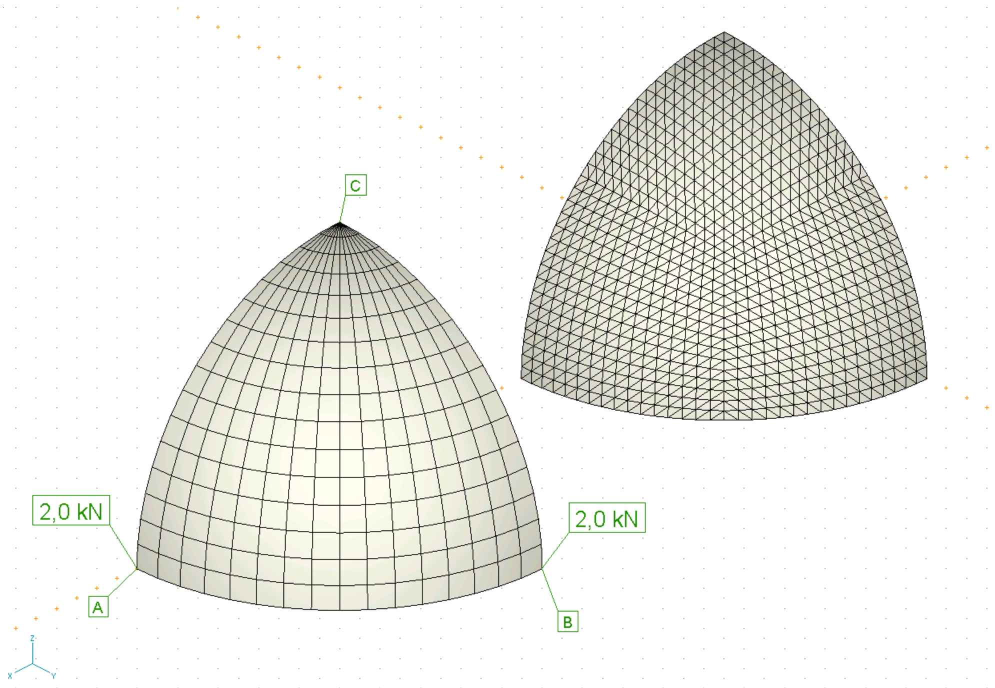
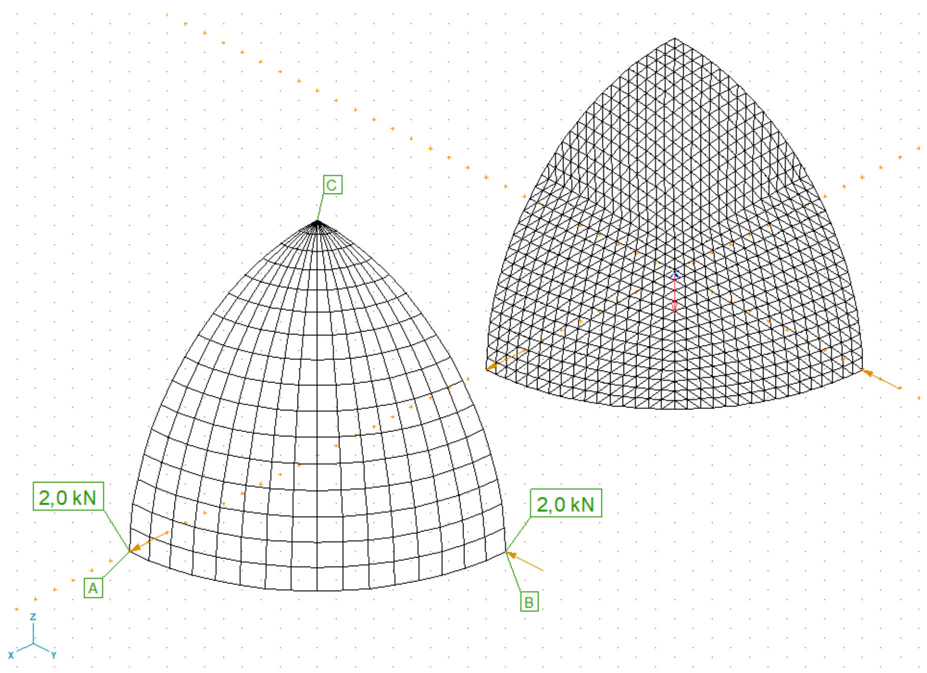
Target	m_x, m_y
Results	(see table below)

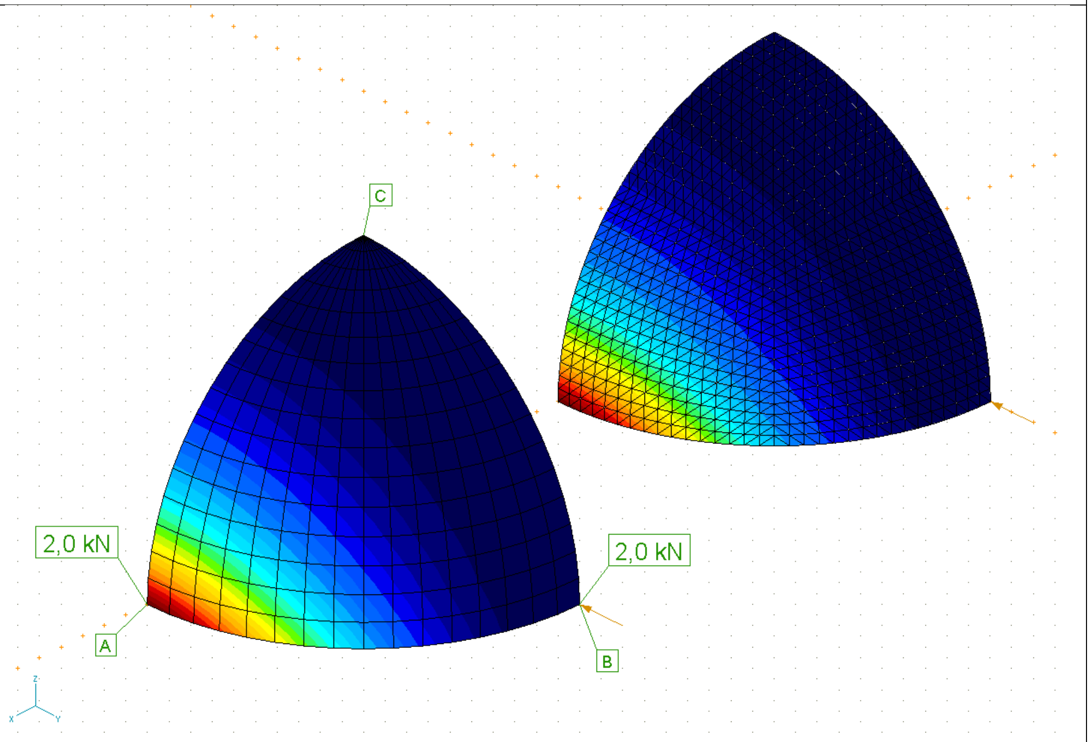
Results	Theory	AxisVM	%
$m_{x,1}$ [kNm/m]	11,50	11,48	-0,17
$m_{y,1}$ [kNm/m]	11,50	11,48	-0,17
$m_{x,2}$ [kNm/m]	33,40	33,23	-0,51
$m_{x,3}$ [kNm/m]	17,90	17,83	-0,39
$m_{y,4}$ [kNm/m]	25,70	25,53	-0,66

Reference:

S. Timoshenko and S. Woinowsky-Krieger: Theory of Plates And Shells

Software Release Number: X5r1
Date: 07. 11. 2018.
Tested by: InterCAD
File name: hemisphere.axs

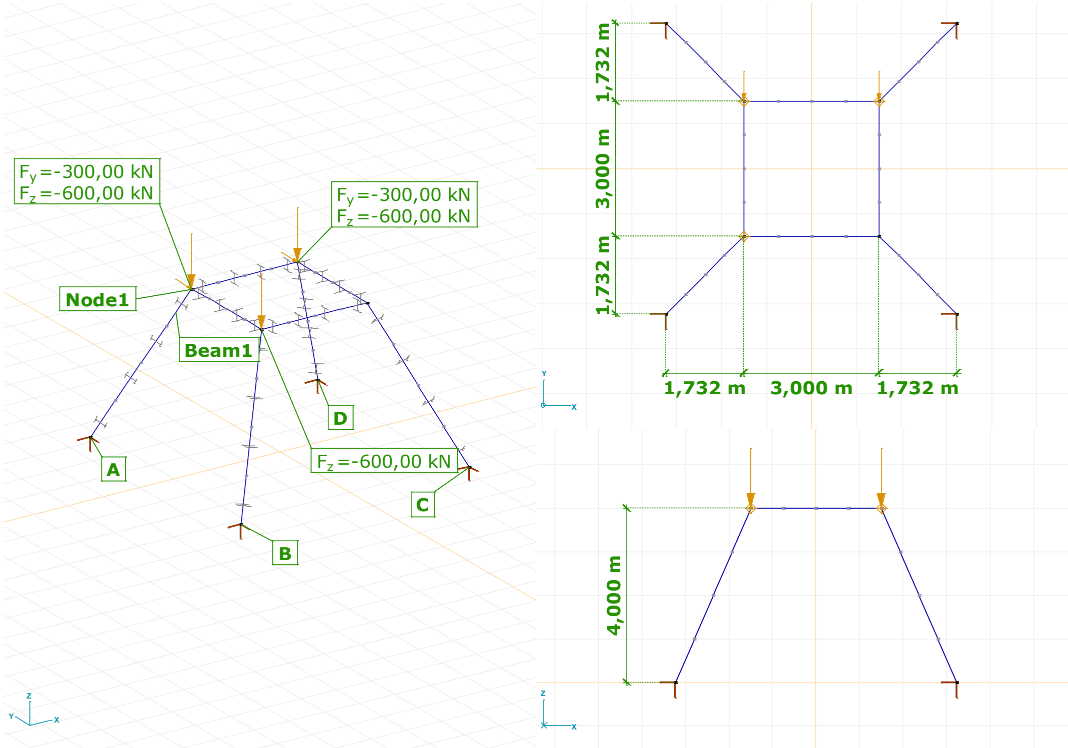
Thema	Hemisphere displacement.
Analysis Type	Linear analysis.
Geometry	 Hemisphere (Axonometric view) t = 0,04 m
Loads	Point load P = 2,0 kN 
Boundary	eX = eY = eZ = fiX = fiY = fiZ= 0 at C

Conditions	Symmetry in X-Z plane on A-C edge Symmetry in Y-Z plane on B-C edge
Material Properties	E = 6825 kN / cm^2 ν = 0,3
Element types	Shell element 1.) guadrilateral parabolic 2.) triangle parabolic
Target	e_x at point A
Results	

	e_x [m]	e [%]
Theory	0,185	
AxisVM quadrilateral	0,185	0,00
AxisVM triangle	0,182	-1,62

Nonlinear static

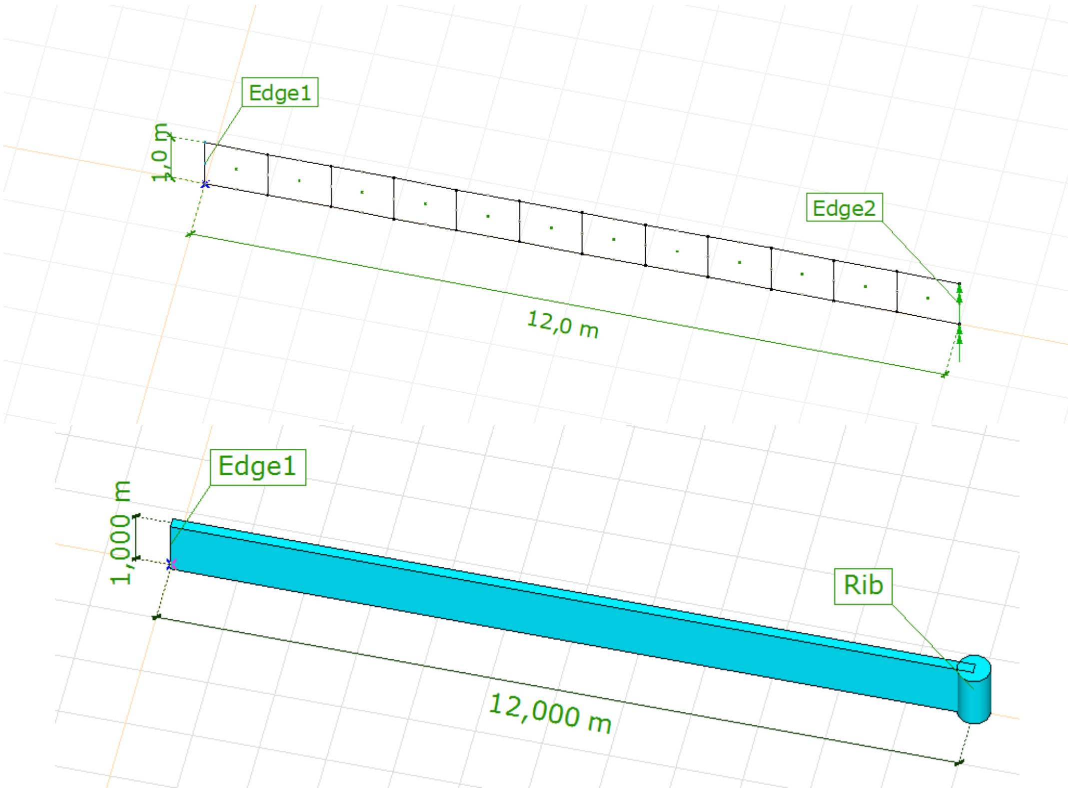
Date: 07. 11. 2018.
Tested by: InterCAD
File name: nonlin1.axs

Thema	3D beam structure.
Analysis Type	Geometrical nonlinear analysis.
Geometry	
Loads	Py = -300 kN Pz = -600 kN
Boundary Conditions	eX = eY = eZ = 0 at A, B, C and D
Material Properties	S 275 E = 21000 kN / cm^2 ν = 0,3
Cross-Section Properties	HEA 300 Ax = 112.56 cm^2 ; Ix = 85.3 cm^4 ; Iy = 18268.0 cm^4 ; Iz = 6309.6 cm^4
Element types	Beam
Target	eX, eY, eZ, at Node1 Nx, Vy, Vz, Tx, My, Mz of Beam1 at Node1

Results	Comparison with the results obtained using Nastran V4

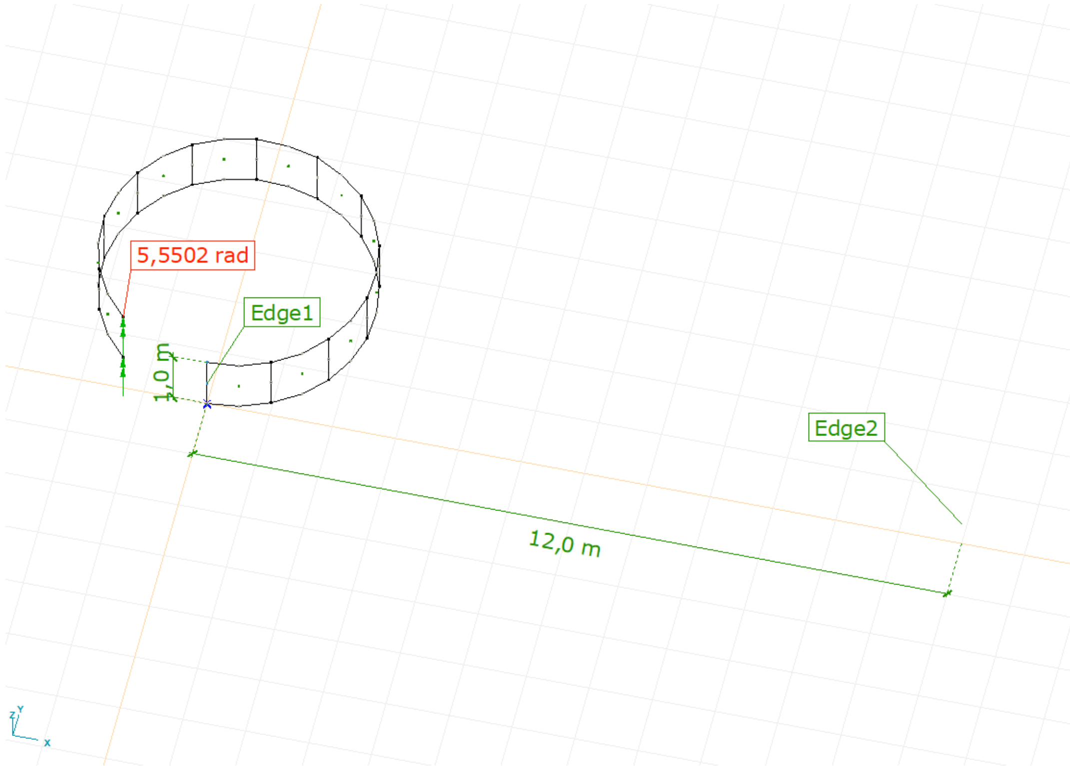
Component	Nastran®	AxisVM	%
eX [mm]	17,898	17,881	-0,09
eY [mm]	-75,702	-75,663	-0,05
eZ [mm]	-42,623	-42,597	-0,06
Nx [kN]	-283,15	-283,25	0,04
Vy [kN]	-28,09	-28,10	0,04
Vx [kN]	-106,57	-106,48	-0,08
Tx [kNm]	-4,57	-4,57	0,00
My [kNm]	-519,00	-518,74	-0,05
Mz [kNm]	148,94	148,91	-0,02

Software Release Number: X5r1
Date: 07. 11. 2018.
Tested by: InterCAD
File name: nonlin2.axs

Thema	Plate with fixed end and bending moment.
Analysis Type	Geometrical nonlinear analysis.
Geometry	
Loads	Mz = 2600 kNm (2x1300 Nm) acting on Edge2
Boundary Conditions	eX = eY = eZ = fiX = fiY = fiZ = 0 along Edge1 (Use Constrained nodes instead of line support; Nodal DOF on Edge 1: Fixed node)
Material Properties	E = 20000 N / mm^2 ν = 0
Cross Section Properties	Plate thickness: 150 mm Rib on Edge2: circular D = 500 mm (for distributing load to the mid-side-node)
Element types	Parabolic quadrilateral shell (heterosis type) Rib on Edge2 for distributing load to the mid-side-node

Target: φz at Edge2

Results



Theoretical results based on the differential equation of the flexible beam:

$$\left.\begin{aligned}\kappa &= \frac{M}{I_{plate}E_{plate}}\\ \varphi_z &= \kappa\cdot\ell_{plate}\end{aligned}\right\}\rightarrow \varphi_z = \frac{M\,\ell_{plate}}{I_{plate}E_{plate}}$$

$$I_{plate} = \frac{a\,b^3}{12} = \frac{1\cdot 0.15^3}{12} = 2.8125\cdot 10^{-4}$$

$$E_{plate} = 2\cdot 10^{10}\ N/m^2$$

$$\ell_{plate} = 12\ m$$

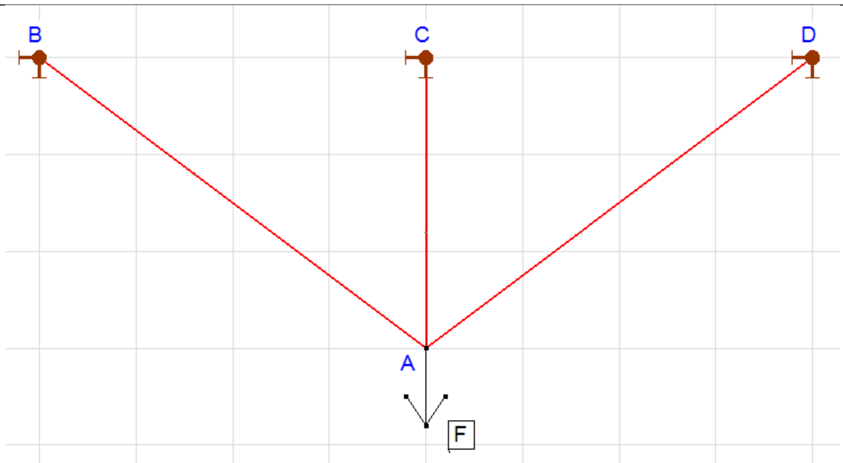
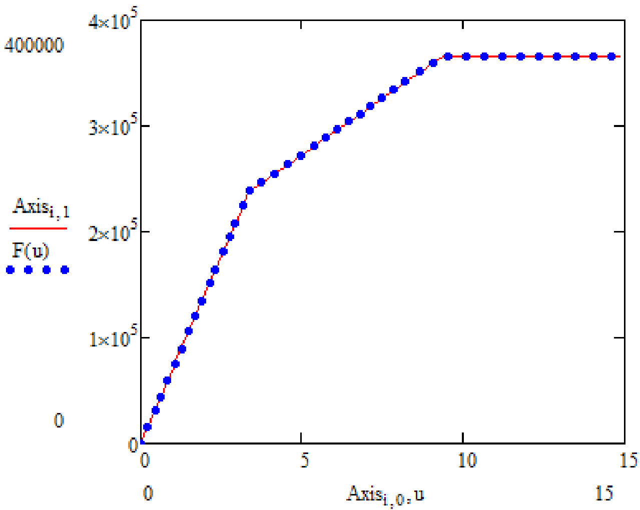
$$M = 2.6\cdot 10^{6}\ Nm$$

$$\varphi_z = \frac{2.6\cdot 10^{6}\cdot 12}{2.8125\cdot 10^{-4}\cdot 2\cdot 10^{10}} = 5.5467\ rad$$

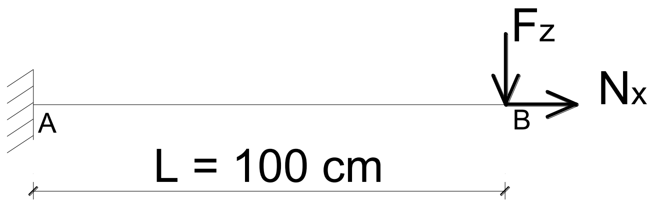
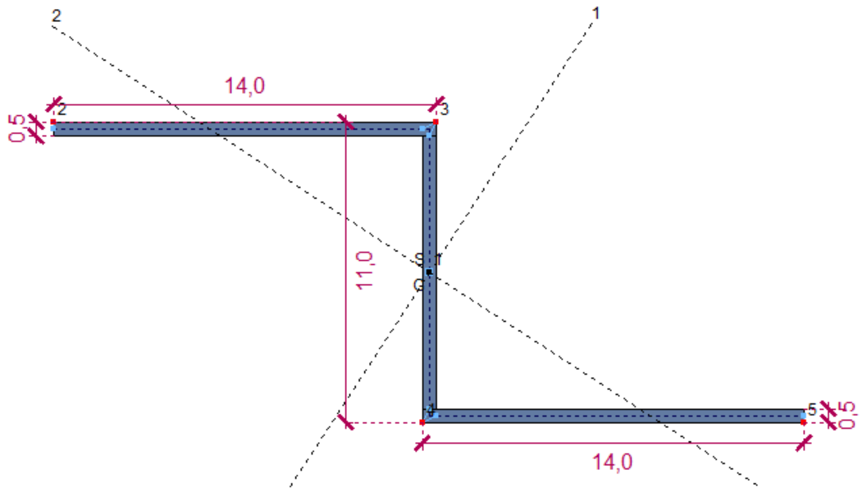
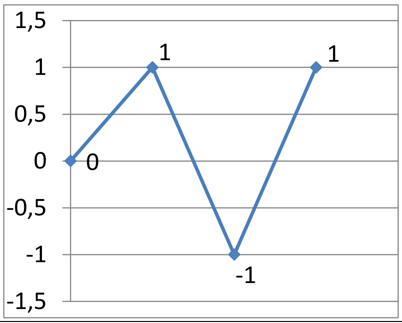
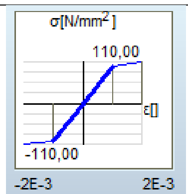
Comparison the AxisVM result with the theoretical one:

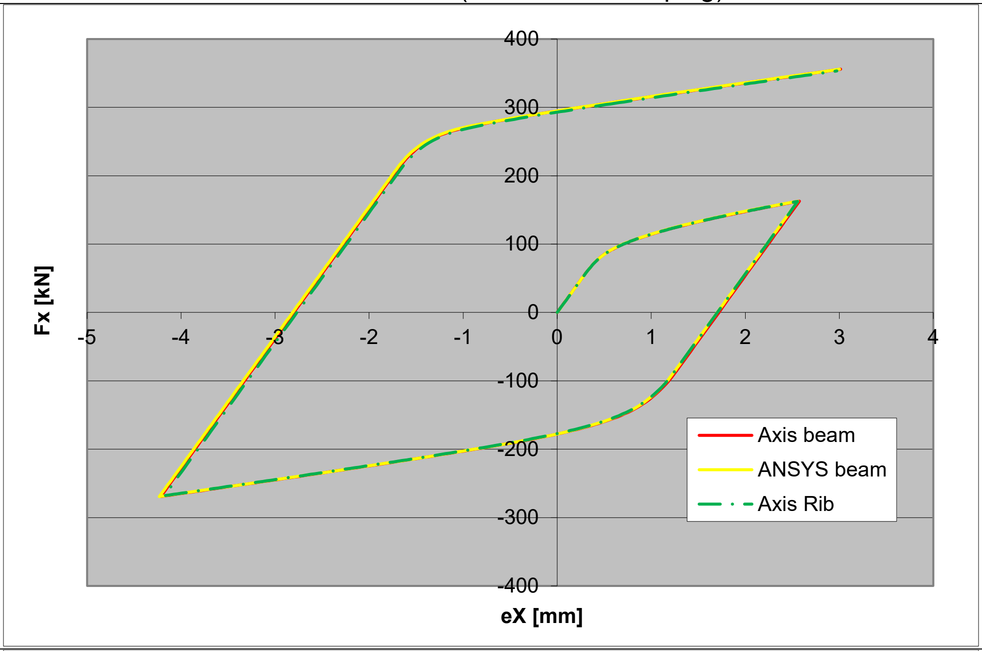
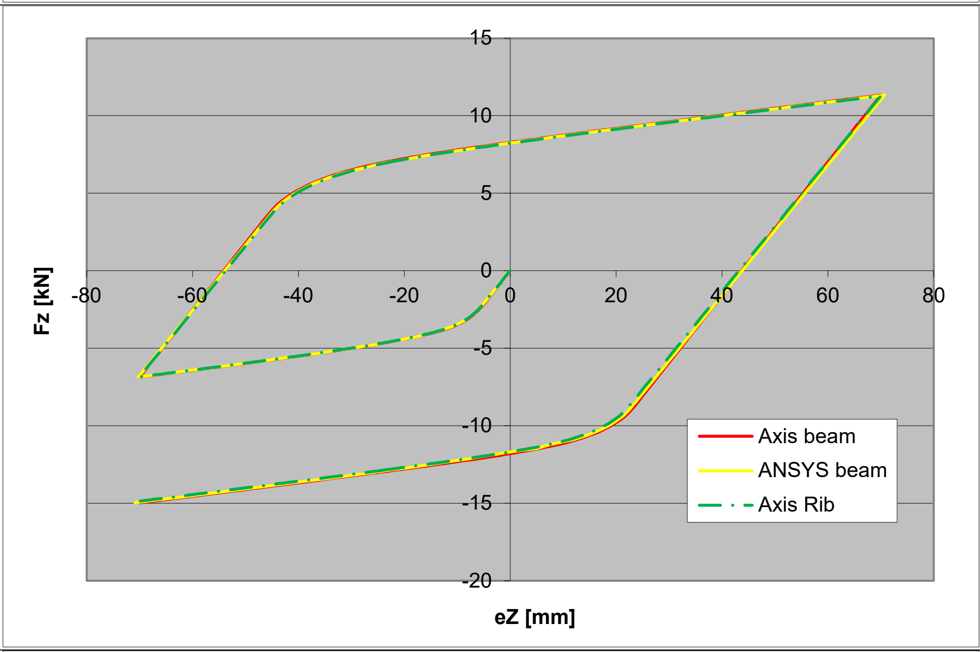
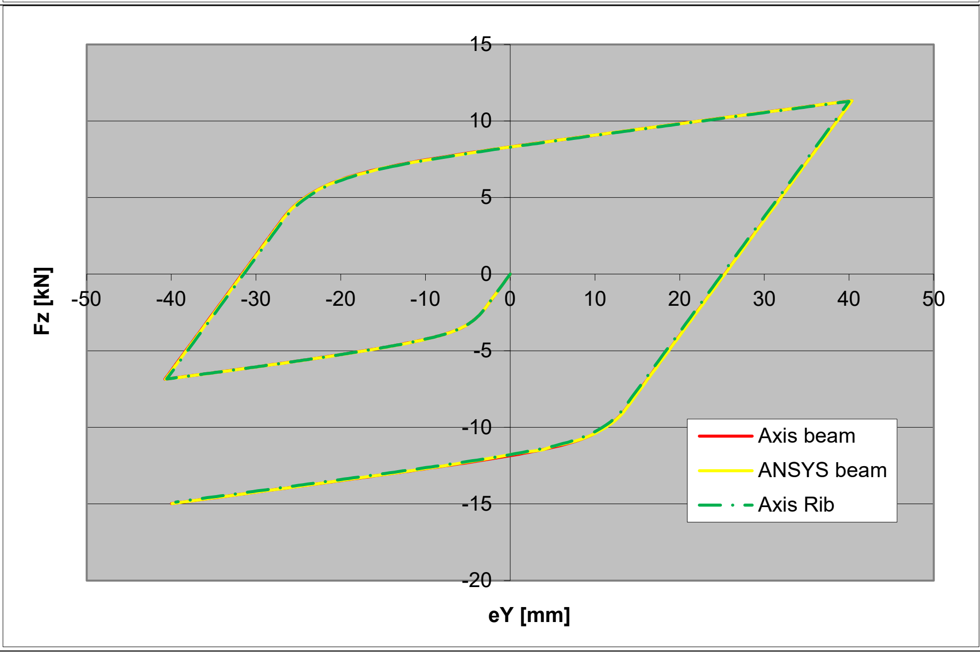
Component	Theory	AxisVM	%
fiZ [rad]	5,5467	5,5502	0,06

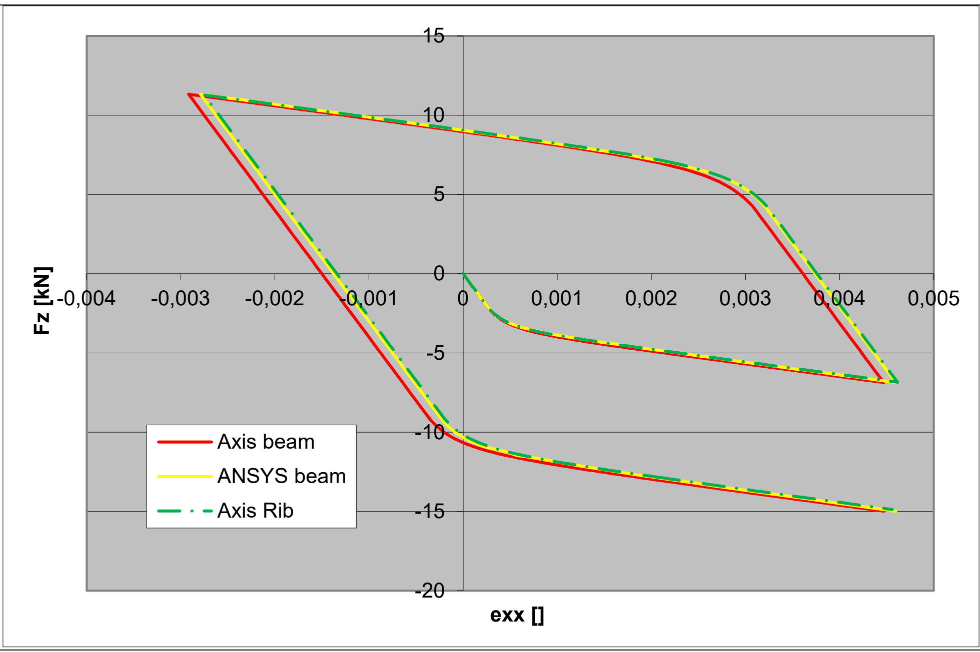
Software Release Number: X5r1
Date: 07. 11. 2018.
Tested by: InterCAD
File name: Plastic_1.axs

Thema	Plastic material
Analysis Type	Nonlinear static analysis
Geometry	 Cross-section: D = 30mm
Loads	Axial force at A: N Solution control: Displacement at A
Boundary Conditions	eX = eY = eZ = 0 at B, C and D
Material Properties	S 235 E = 21000 kN / cm^2 ν = 0,3 Linear elastic – perfectly plastic material model
Element types	Truss element
Target	Check the load – vertical displacement (A) curve
Results	 Analytical results: [u;F(U)] AxisVM: [$Axis_{i,1}$; $Axis_{i,0}$]

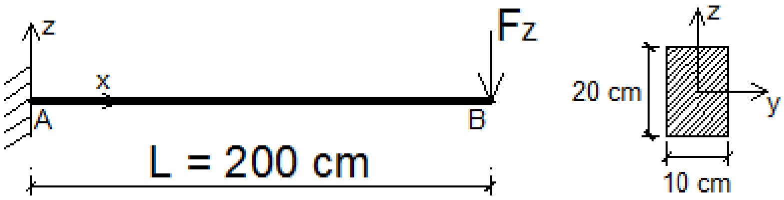
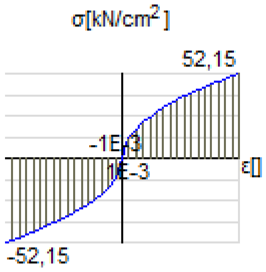
Software Release Number: X5r1
Date: 07. 11. 2018.
Tested by: InterCAD
File name: Plastic_2.axs

Thema	Clamped beam with plastic material under cyclic loading
Analysis Type	Nonlinear static analysis
Geometry	  Cross-section: Z = 30mm
Loads	N_x = 63,333 kN; Fz = 2,666 kN Solution control: Displacement at B ez = -70 mm Increment function: 
Boundary Conditions	eX = eY = eZ = fiX = fiY = fiZ = 0 at A
Material Properties	Steel E = 100000 kN/cm^2; E_T = 1000 kN/cm^2; σ_y = 10 kN/cm^2 ν = 0,3 Linear elastic –plastic material model Hardening rule: Isotropic hardening 
Element types	Beam element
Target	Check the load –displacements and beam strains curves
Results	AxisVM: • Beam element • Rib element (shear deformation is taken into account)

	• ANSYS 14.0 – Beam element (unrestrained warping)
	
	
	


Fz [kN]
exx []
15
10
5
0
-5
-10
-15
-20
-0,004
-0,003
-0,002
-0,001
0
0,001
0,002
0,003
0,004
0,005
Axis beam
ANSYS beam
Axis Rib

Software Release Number: X5r1
Date: 29. 01. 2018.
Tested by: InterCAD
File name: matnl_01_xx (*xx – element type*)

Thema	Clamped beam with *symmetric nonlinear* material model
Analysis Type	Nonlinear static analysis
Geometry	
Loads	Fz = 200 kN Solution control: Force Increment function: Equal increments
Boundary Conditions	eX = eY = eZ = fiX = fiY = fiZ = 0 at A
Material Properties	Steel – Strain energy based (*NLE*) Steel – Von Mises (*VM*) Material model function: $\sigma = 400 \cdot \sqrt{\varepsilon}$ Discrete function assignment per ε = 0.001 [] ν = 0,3 
Element types / File name	Beam/Rib element: *matnl_01_beam-rib_NLE.axs*, *matnl_01_beam-rib_VM.axs* Plate element (heterosis type): *matnl_01_plate_NLE.axs*, *matnl_01_plate_VM.axs* Membrane element: *matnl_01_membrane_NLE.axs*, *matnl_01_membrane_VM.axs*
Target	Check vertical displacements (B) and stresses (A)

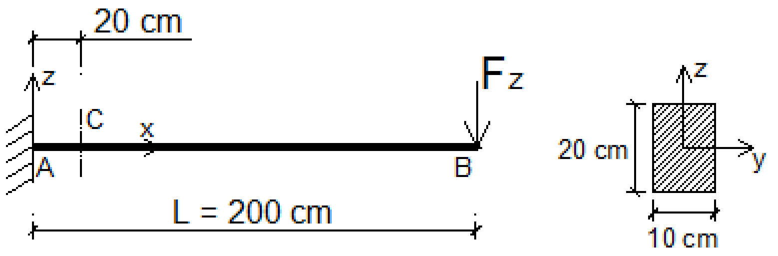
Results

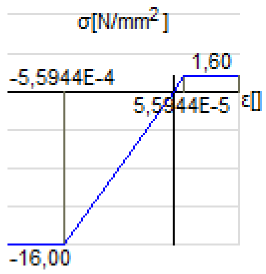
Analytical background: Appendix A;

Yield criterion	***Strain energy based***		***Von Mises***	
Type of element	e_B [mm]	[%]	e_B [mm]	[%]
Analytical	156,4		156,4	
Beam	157,98	1,01	147,87	-5,45
Rib	158,48	1,33	148,36	-5,14
Plate TRIA	158,98	1,65	158,68	1,46
Membrane TRIA	158,34	1,24	163,49	4,53

Yield criterion	***Strain energy based***		***Von Mises***	
Type of element	σ_A [kN/cm^2]	[%]	σ_A [kN/cm^2]	[%]
Analytical	50		50	
Beam	49,9	-0,20	47,95	-4,10
Rib	49,9	-0,20	47,97	-4,06
Plate TRIA	49,84	-0,32	49,6	-0,80
Membrane TRIA	49,75	-0,50	48,37	-3,26

Software Release Number: X4r3
Date: 29. 01. 2018.
Tested by: InterCAD
File name: matnl_02_xx (xx – element type)

<table>
<tr><td>Thema</td><td>Clamped beam with asymmetric nonlinear material model</td></tr>
<tr><td>Analysis Type</td><td>Nonlinear static analysis</td></tr>
<tr><td>Geometry</td><td>


</td></tr>
<tr><td>Loads</td><td>Fz = 1200 N;
Solution control: Force
Increment function: Equal increments</td></tr>
<tr><td>Boundary Conditions</td><td>eX = eY = eZ = fiX = fiY = fiZ = 0 at A</td></tr>
<tr><td>Material Properties</td><td>Concrete – Bresler-Pister (BP)
Other – Strain energy based (NLE)
E = 28600 N/mm^2; E_T = 0 N/mm^2;
σ_{yT} = 1,6 N/mm^2; σ_{yC} = 16 N/mm^2;
C_{yB} = 1,2 (Bresler-Pister);
ν = 0;


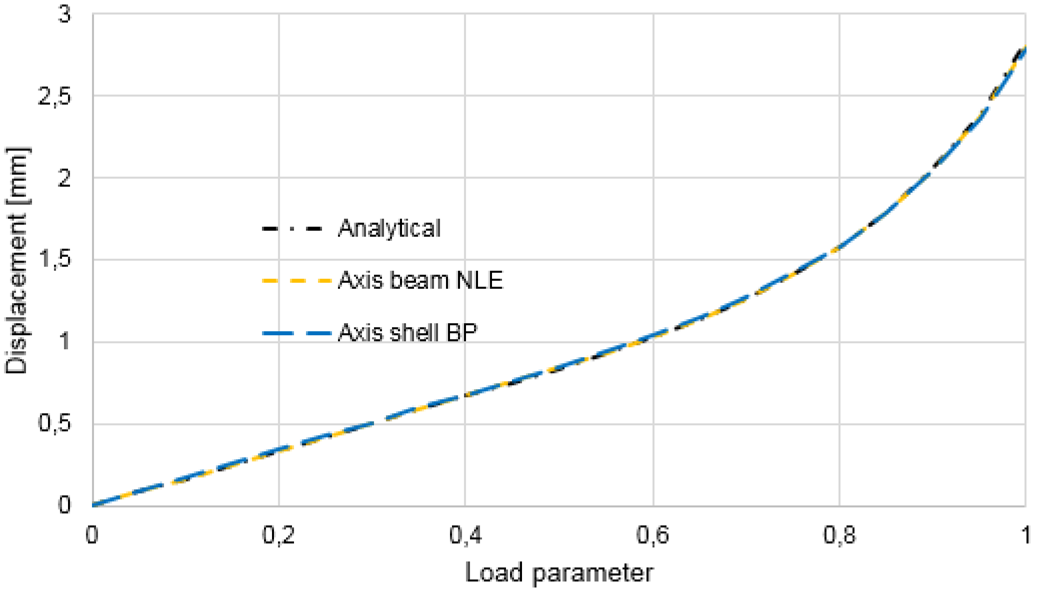
</td></tr>
<tr><td>Element types / File name</td><td>Beam/Rib element — matnl_02_beam-rib_NLE.axs, matnl_02_beam-rib_BP.axs
Shell element (heterosis type) — matnl_02_shell_NLE.axs, matnl_02_shell_BP.axs</td></tr>
<tr><td>Target</td><td>Check vertical displacements (B) and stresses (C), length of plastic zone (x)</td></tr>
</table>

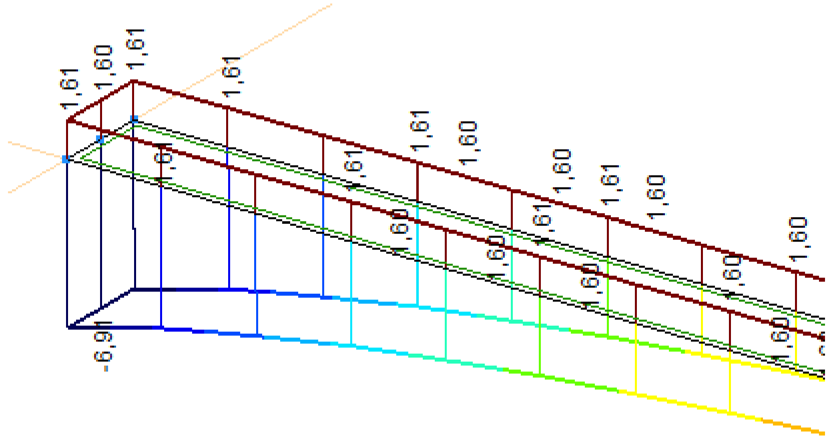
Results

Analytical background: Appendix A;

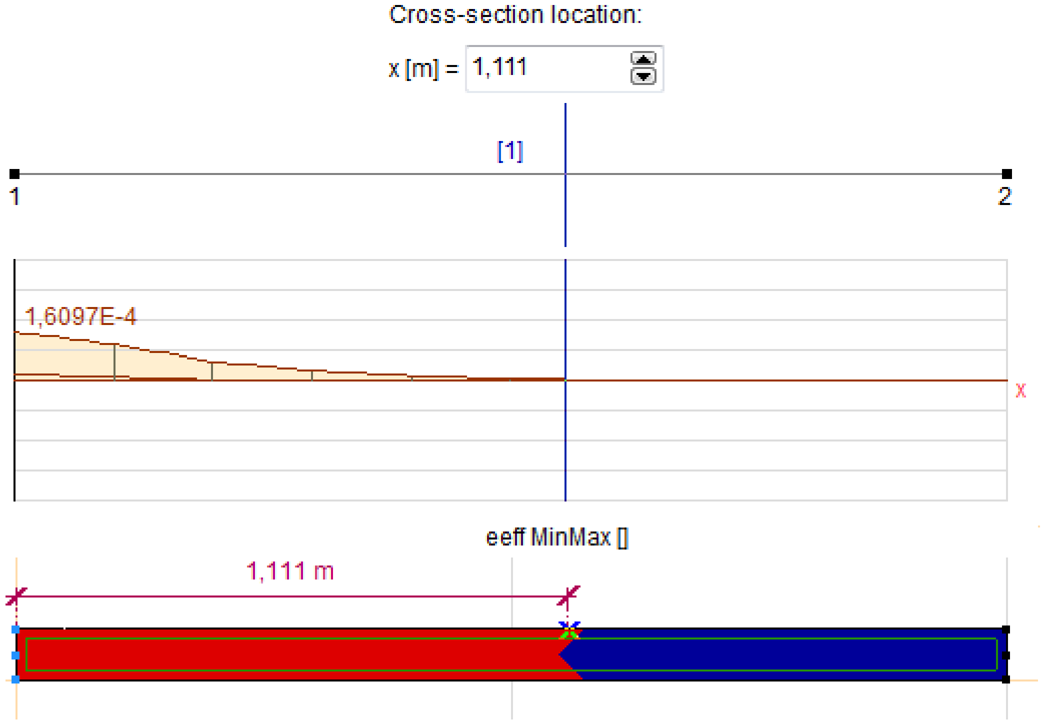
Yield criterion	***Strain energy based***		***Bresler Pister***	
Type of element	e_B [mm]	[%]	e_B [mm]	[%]
Analytical	2,833		2,833	
Beam	2,798	-1,24	2,796	-1,31
Rib	2,841	0,28	2,837	0,14
Shell	2,903	2,47	2,792	-1,45

Yield criterion	***Strain energy based***		***Bresler Pister***	
Type of element	$\sigma_{C,min}$ [kN/cm^2]	[%]	$\sigma_{C,min}$ [kN/cm^2]	[%]
Analytical	4,98		4,98	
Beam	5,03	1,00	5,02	0,8
Rib	4,90	-1,61	4,90	-1,61
Shell	5,01	0,60	4,90	-1,61



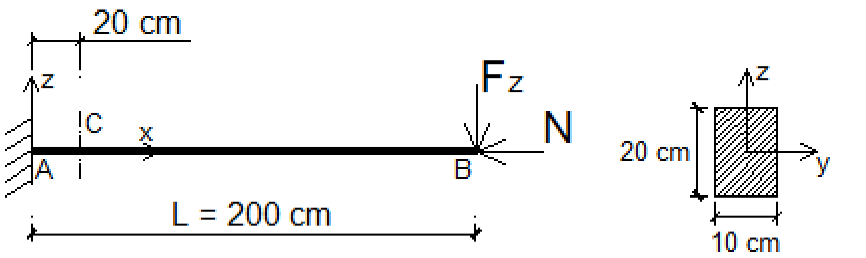
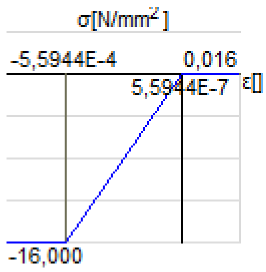


Axis shell NLE model – top and bottom S_{xx} [N/mm^2]



Effective plastic strain of Beam and shell (top) with Bresler-Pister material
Analytical result for ***x*** = 1,111 m (plastic zone)

Software Release Number: X4r3
Date: 29. 01. 2018.
Tested by: InterCAD
File name: matnl_03_xx (xx – element type)

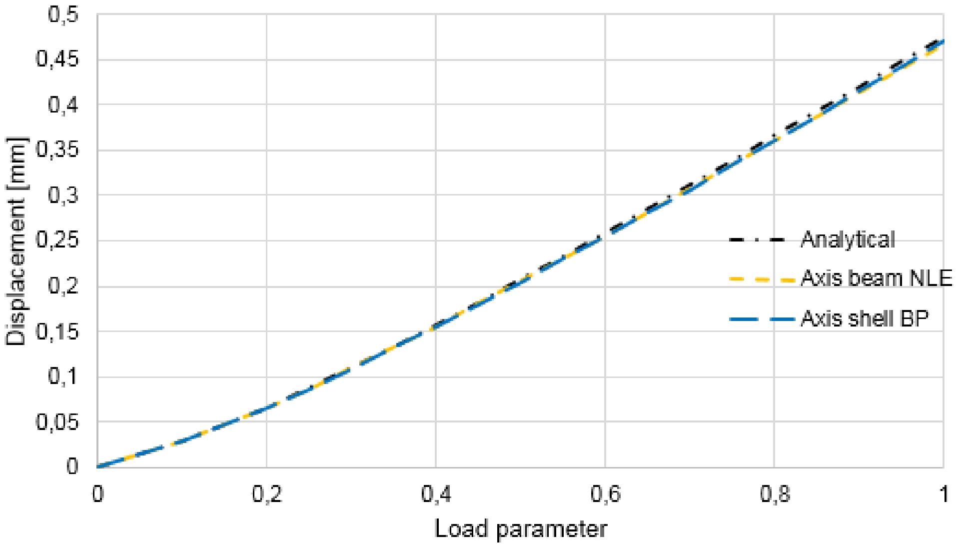
Thema	Clamped beam with *only compression* material model
Analysis Type	Nonlinear static analysis
Geometry	
Loads	Fz =200 N; N = 5000 N Solution control: Force Increment function: Equal increments
Boundary Conditions	eX = eY = eZ = fiX = fiY = fiZ = 0 at A
Material Properties	Concrete – Bresler-Pister (*BP*) Other – Strain energy based (*NLE*) E = 28600 N/mm^2; E_T = 0 N/mm^2; σ_{yT} = 0,016 N/mm^2; σ_{yC} = 16 N/mm^2; C_{yB} = 1,2 (Bresler-Pister); ν = 0; 
Element types / File name	Beam/Rib element — *matnl_03_beam-rib_NLE.axs*, *matnl_03_beam-rib_BP.axs* Shell element (heterosis type) — *matnl_03_shell_NLE.axs*, *matnl_03_shell_BP.axs*
Target	Check vertical displacements (B) and stresses (C), length of plastic zone (x)

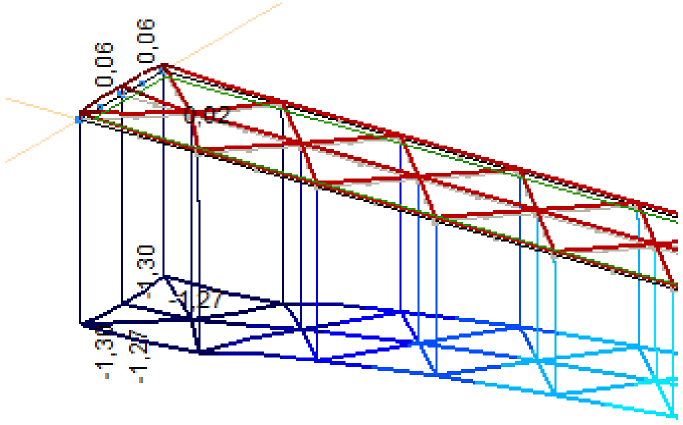
Results

Analytical background: Appendix A;

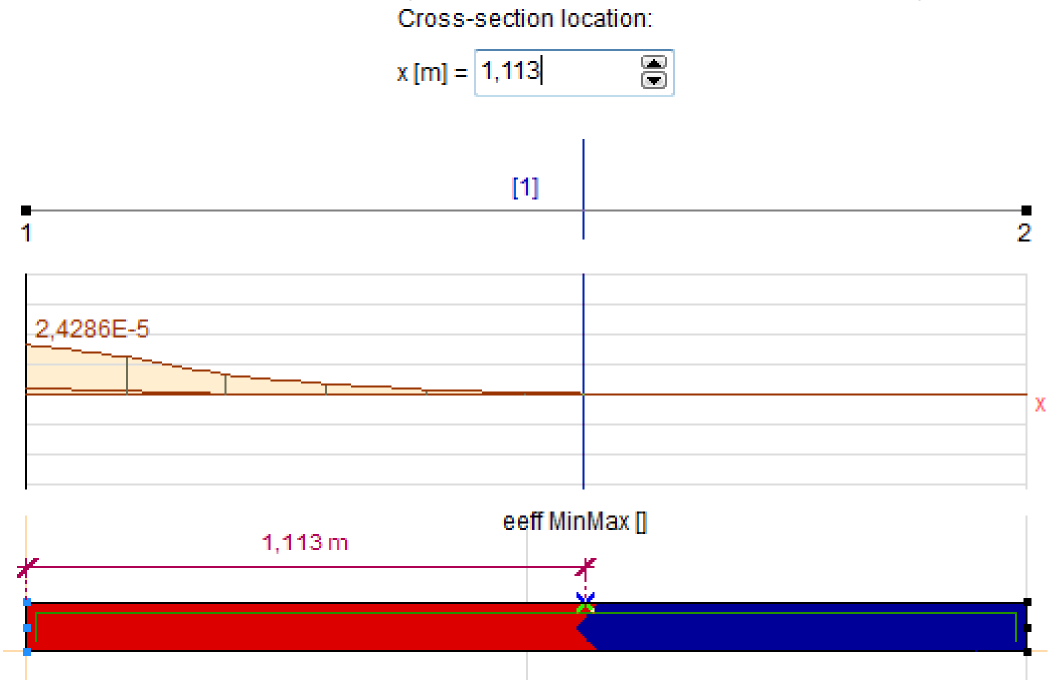
Yield criterion	***Strain energy based***		***Bresler Pister***	
Type of element	e_B [mm]	[%]	e_B [mm]	[%]
Analytical	0,475		0,475	
Beam	0,468	-1,90	0,466	-1,97
Rib	0,475	-0,07	0,473	-0,50
Shell	0,484	1,61	0,471	-0,92

Yield criterion	***Strain energy based***		***Bresler Pister***	
Type of element	$\sigma_{C,min}$ [N/mm^2]	[%]	$\sigma_{C,min}$ [N/mm^2]	[%]
Analytical	1,097		1,097	
Beam	1,088	-0,82	1,086	-1,0
Rib	1,067	-2,73	1,066	-2,82
Shell	1,085	-1,09	1,076	-1,97

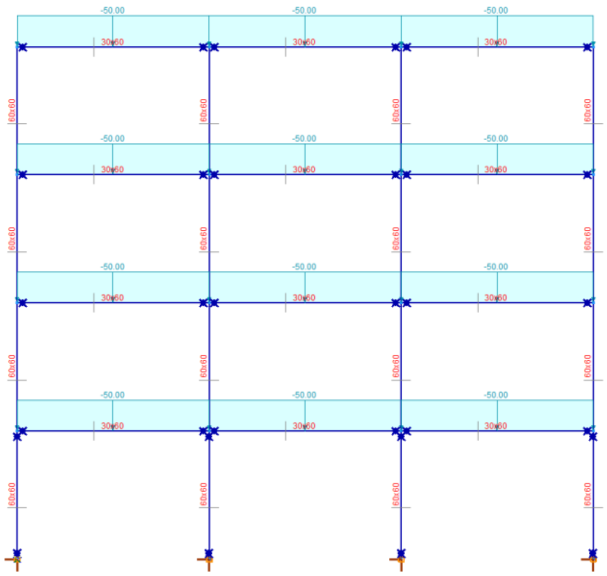
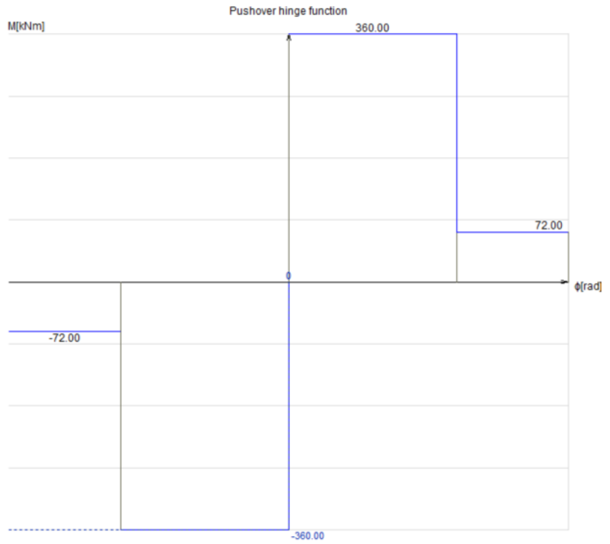


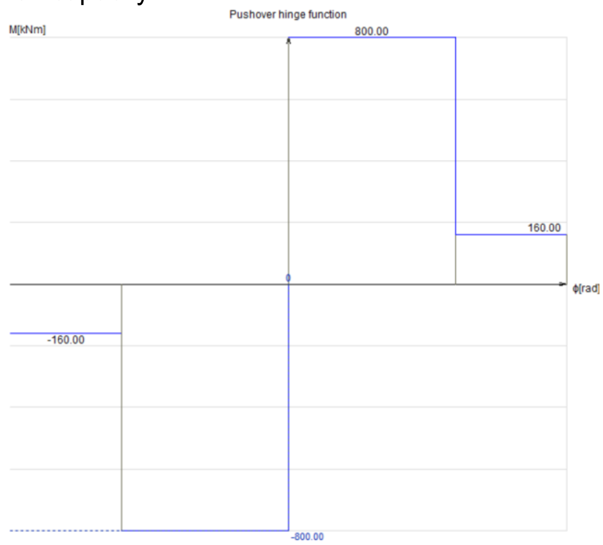
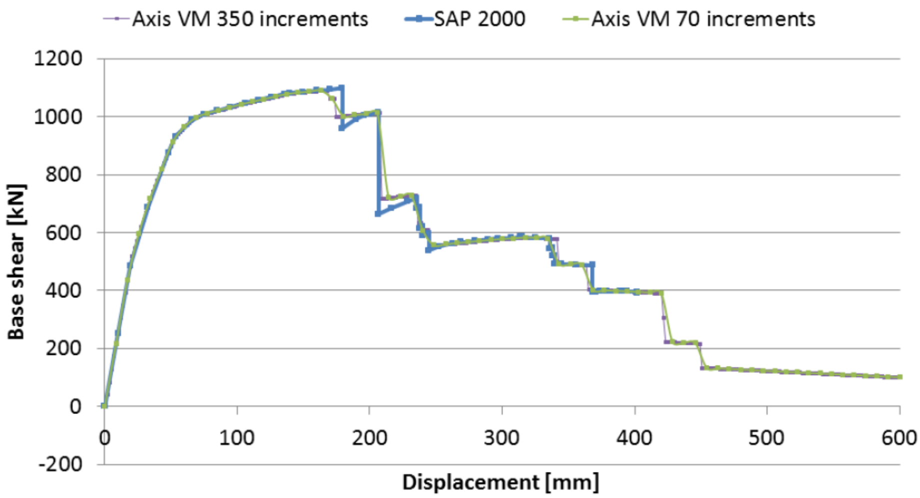


Axis shell NLE model – top and bottom S_{xx} [N/mm^2]

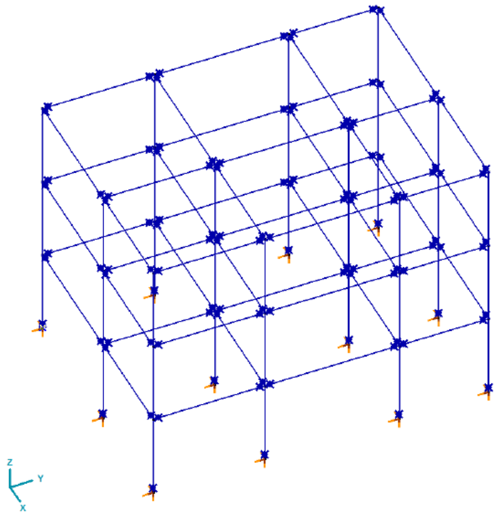
	 ***Effective plastic strain of Beam and shell (top) with Bresler-Pister material*** Analytical result for ***x*** = 1,113 m (plastic zone)

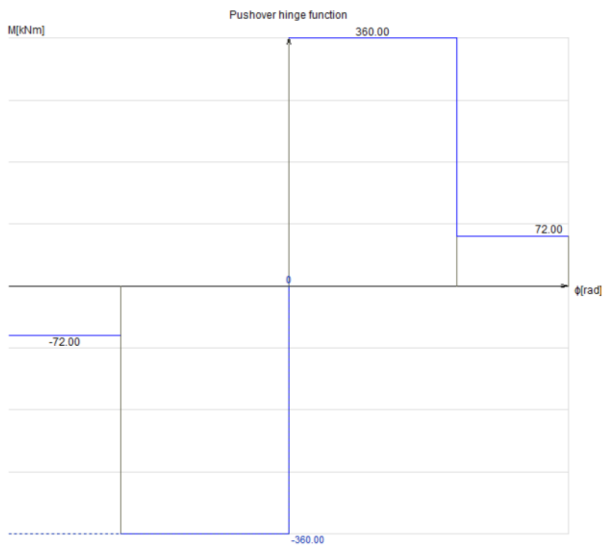
Software Release Number: X5r2
Date: 24. 06. 2019.
Tested by: InterCAD
File name: push_2D_RC_frame.axs

Thema	Pushover – 2D frame
Analysis Type	Nonlinear static analysis
Geometry	three bays with 6m width and 4m height 
Loads	50 kN/m distributed load on the beams
Boundary Conditions	rigid supports
Material Properties	C25/30 concrete
Elements	Beam elements: beam section: 30x60 cm rectangular; column section: 60x60 cm square Plastic hinges at beam ends: • moment resistance: 360 kNm initially, then 72 kNm • no hardening, sudden loss of strength • infinite rotation capacity 

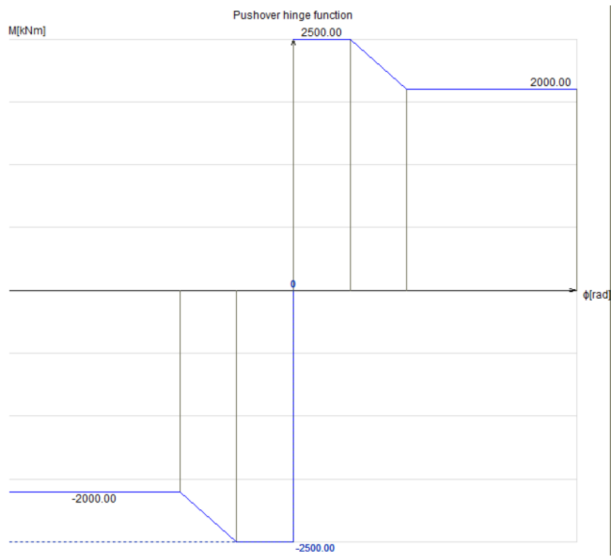
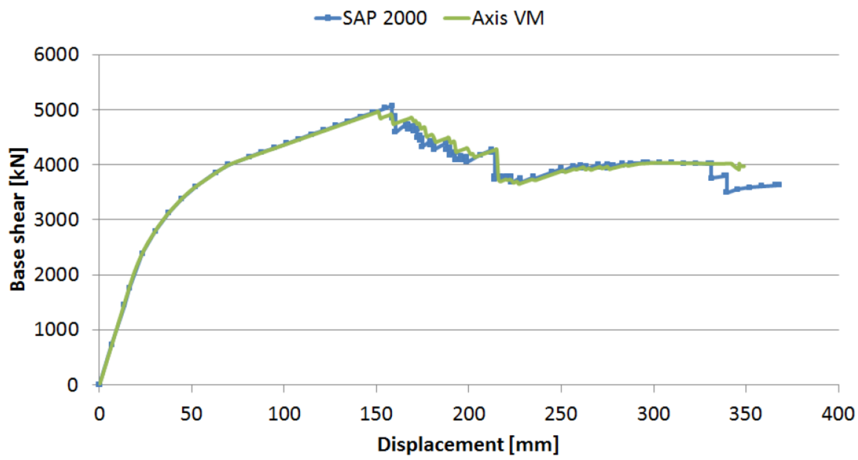
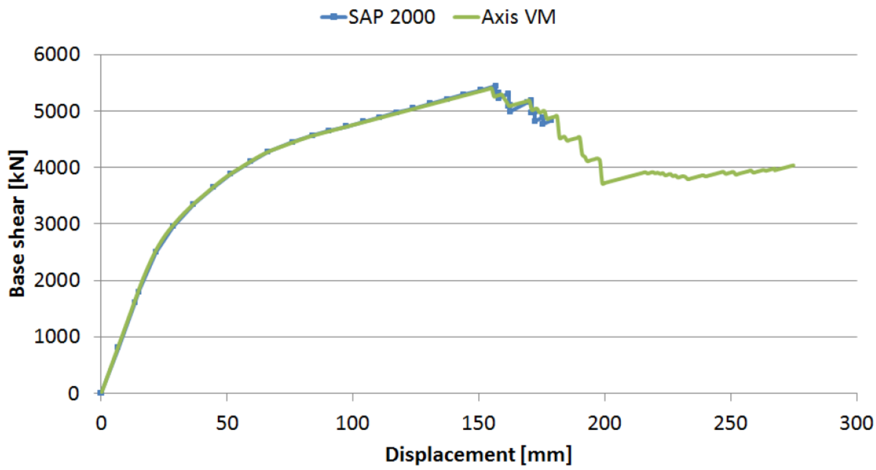
<table>
<tr><td></td><td>Plastic hinges at column bases:
moment resistance: 800 kNm initially, then 160 kNm
no hardening, sudden loss of strength
infinite rotation capacity

</td></tr>
<tr><td>Target</td><td>Pushover analysis – 600 mm top displacement
Comparison with SAP 2000 results</td></tr>
<tr><td>Results</td><td>
</td></tr>
</table>

Software Release Number: X5r2
Date: 24. 06. 2019.
Tested by: InterCAD
File name: push_3D_RC_frame.axs

<table>
<tr><td>Thema</td><td>Pushover – 3D frame</td></tr>
<tr><td>Analysis Type</td><td>Nonlinear static analysis</td></tr>
<tr><td>Geometry</td><td>two bays in x (6m and 5m) and three bays in y (5m, 6m and 4m) direction

</td></tr>
<tr><td>Loads</td><td>25 kN/m distributed load on the beams</td></tr>
<tr><td>Boundary Conditions</td><td>rigid supports</td></tr>
<tr><td>Material Properties</td><td>C25/30 concrete</td></tr>
<tr><td>Elements</td><td>Beam elements: beam section: 30x60 cm rectangular; column section: 60x60 cm square

Plastic hinges at beam ends:
moment resistance: 360 kNm initially, then 72 kNm
no hardening, sudden loss of strength
infinite rotation capacity


Plastic hinges at column bases:</td></tr>
</table>

	• moment resistance: 2500 kNm initially, then 2000 kNm • no hardening, relaxed loss of strength • infinite rotation capacity 
Target	Pushover analysis Comparison with SAP 2000 results
Results – X direction	
Results – Y direction	

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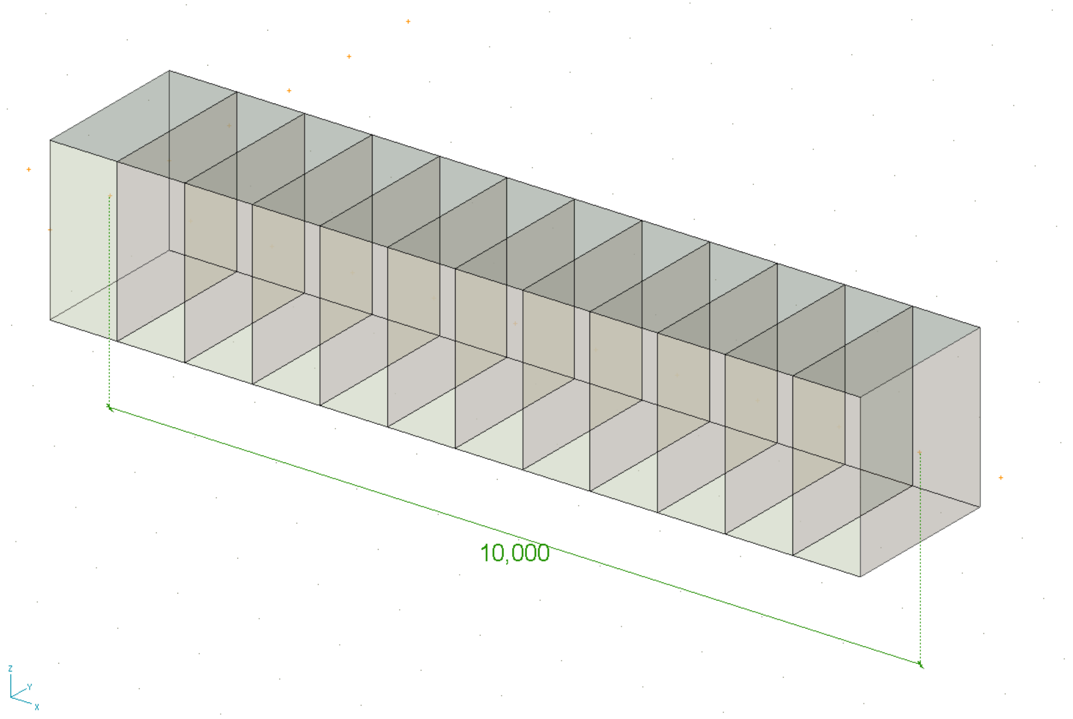
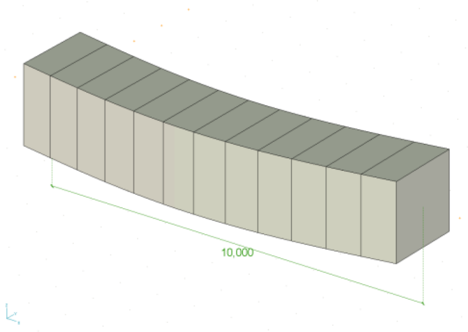
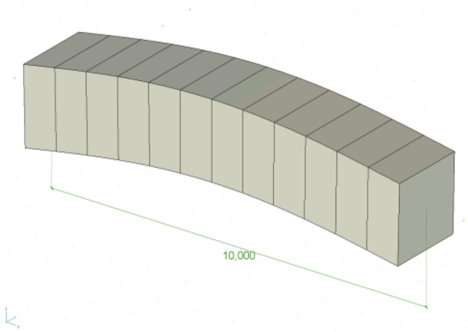
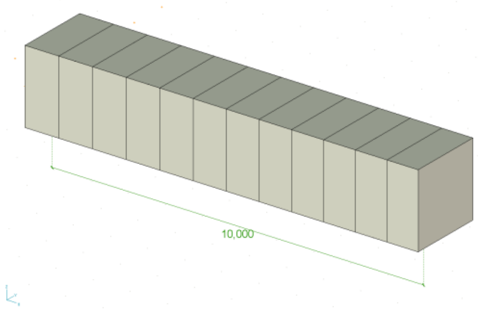
Dynamic

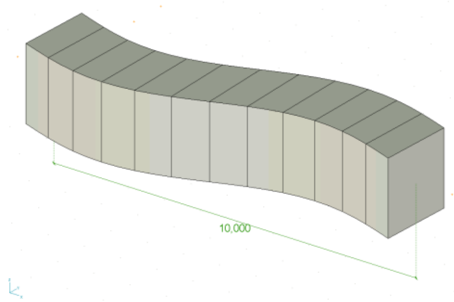
Date: 08. 11. 2018.
Tested by: InterCAD
File name: dynam1.axs

Thema	Deep simply supported beam.
Analysis Type	Vibration analysis.
Geometry	Beam (Axonometric view) Cross section (square 2,0 m x 2,0 m)
Loads	Self-weight (Other option: Apply *Masses only* option on Vibration analysis window)
Boundary Conditions	eX = eY = eZ = fiX = 0 at A eY = eZ = 0 at B
Material Properties	$E = 20000\ kN / cm^2$ $\nu = 0{,}3$ $\rho = 8000\ kg / m^3$
Element types	Rib elemen: Three node beam element (shear deformation is taken into account)
Target	First 7 mode shapes
Results	

Mode 1: f = 43,16 Hz

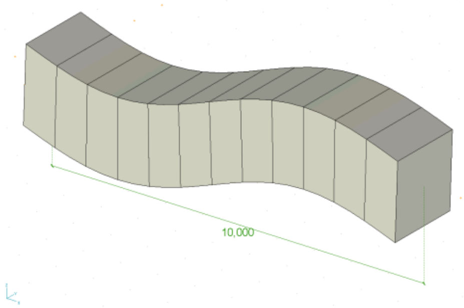
Mode 2: f = 43,16 Hz

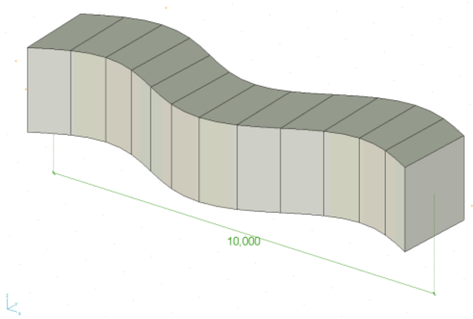




Mode 3: f = 124,01 Hz

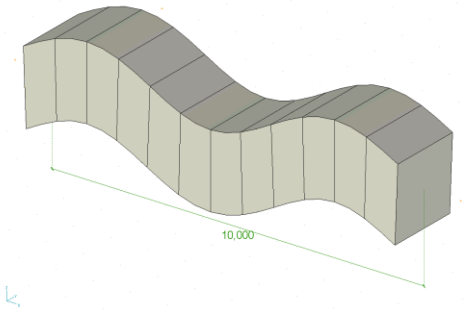
Mode 4: f = 152,50 Hz





Mode 5: f = 152,50 Hz

Mode 6: f = 293,55 Hz

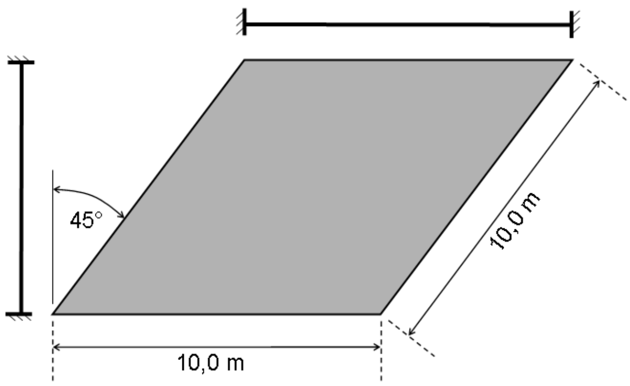
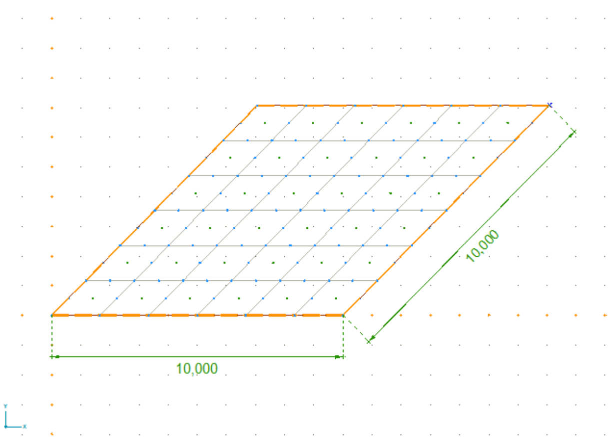


Mode 7: f = 293,55 Hz

Results	Comparison with NAFEMS example

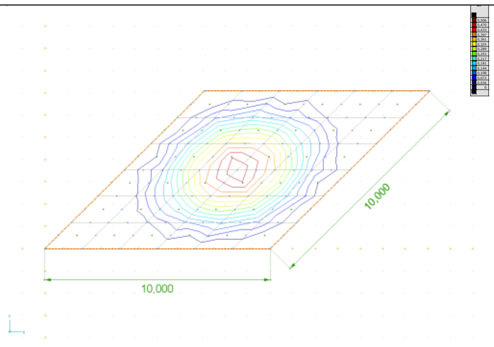
Mode	NAFEMS (Hz)	AxisVM (Hz)	%
1	42,65	43,16	-1,20
2	42,65	43,16	-1,20
3	125,00	124,01	0,79
4	148,31	152,50	-2,83
5	148,31	152,50	-2,83
6	284,55	293,55	-3,16
7	284,55	293,55	-3,16

Software Release Number: X5r1
Date: 07. 11. 2018.
Tested by: InterCAD
File name: dynam2.axs

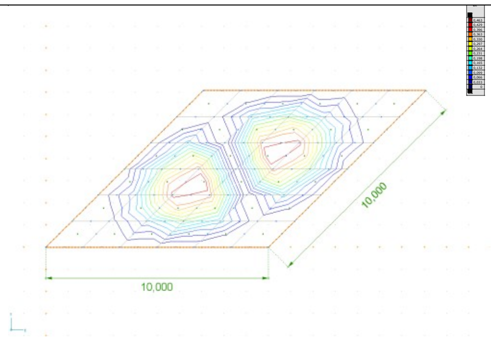
Thema	Clamped thin rhombic plate.
Analysis Type	Vibration analysis.
Geometry	 Top view of plane (thickness = 5,0 cm)
Loads	Self-weight
Boundary Conditions	eX = eY = fiZ = 0 at all nodes (i.e.: eX, eY, fiZ constrained at all nodes; Nodal DOF: Plate in X-Y plane) eZ = fiX = fiY = 0 along the 4 edges (Line support)
Material Properties	E = 20000 kN / cm^2 ν = 0,3 ρ = 8000 kg / m^3
Element types	Parabolic quadrilateral shell element (heterosis type)
Mesh	

Target	First 6 mode shapes

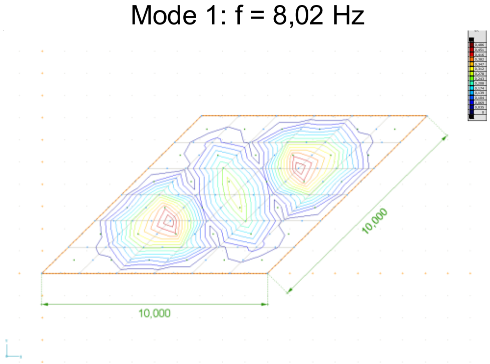
Results



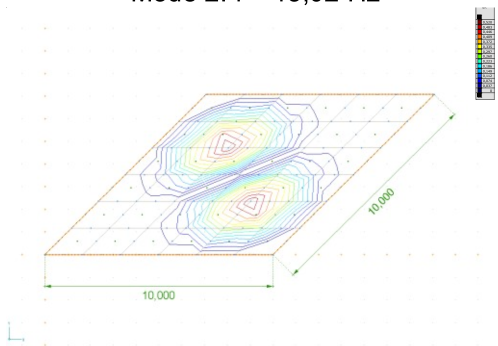
Mode 1: f = 8,02 Hz



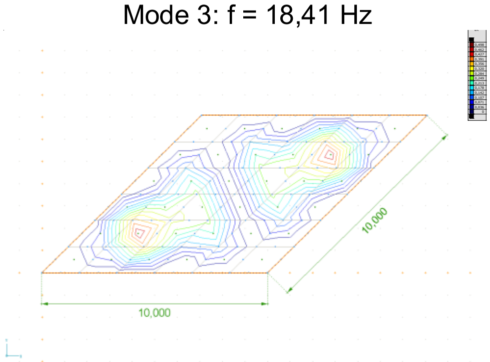
Mode 2: f = 13,02 Hz



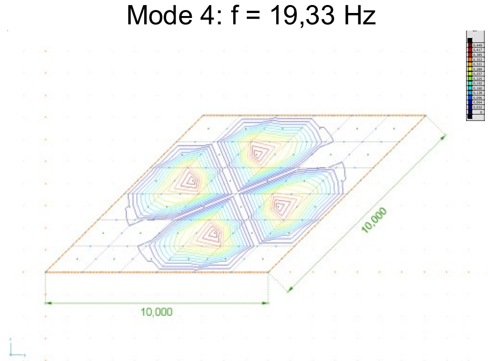
Mode 3: f = 18,41 Hz



Mode 4: f = 19,33 Hz



Mode 5: f = 24,62 Hz



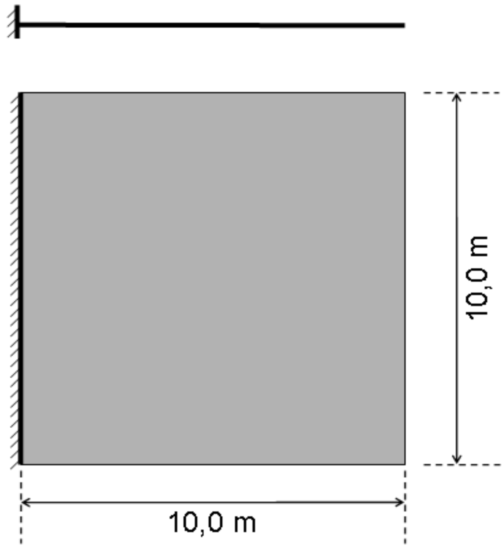
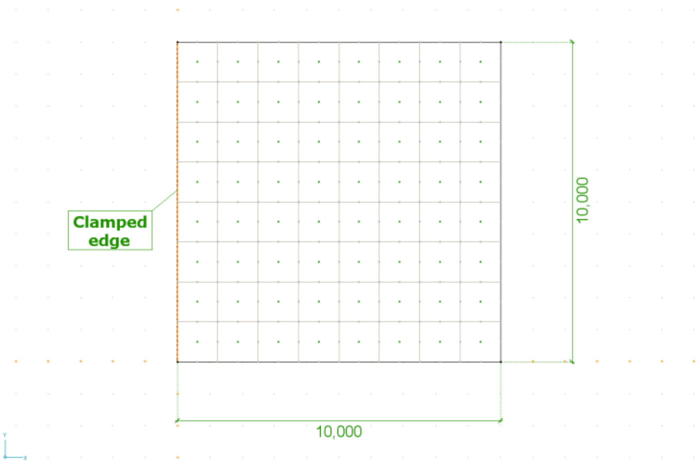
Mode 6: f = 28,24 Hz

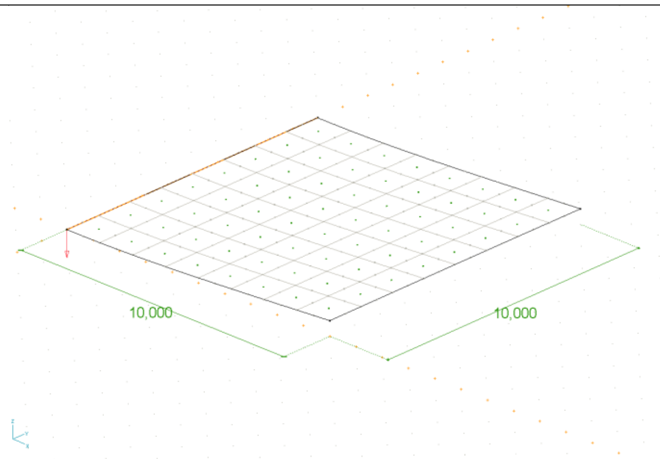
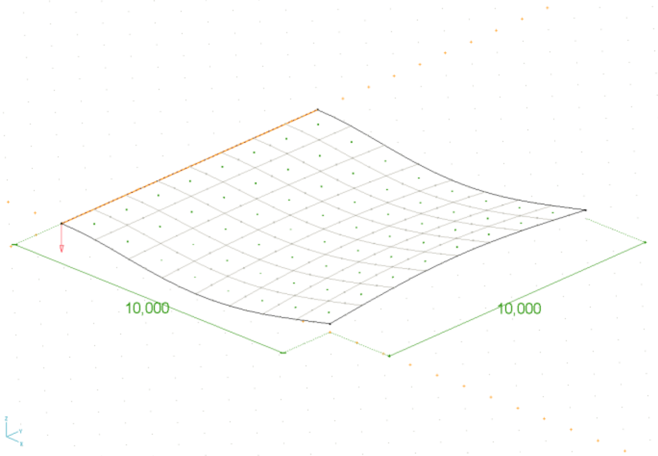
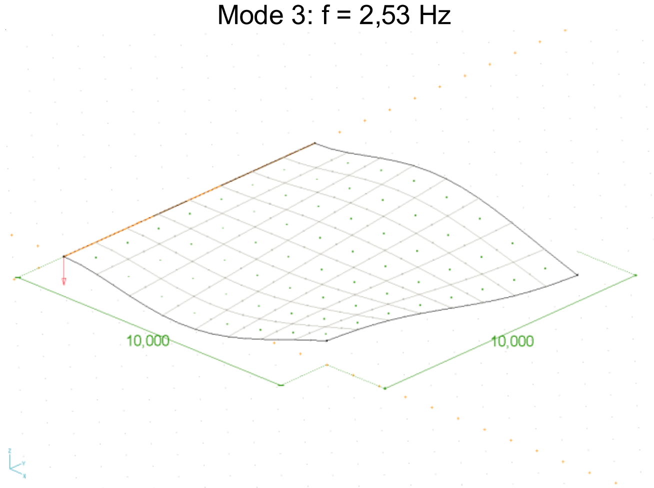
Results

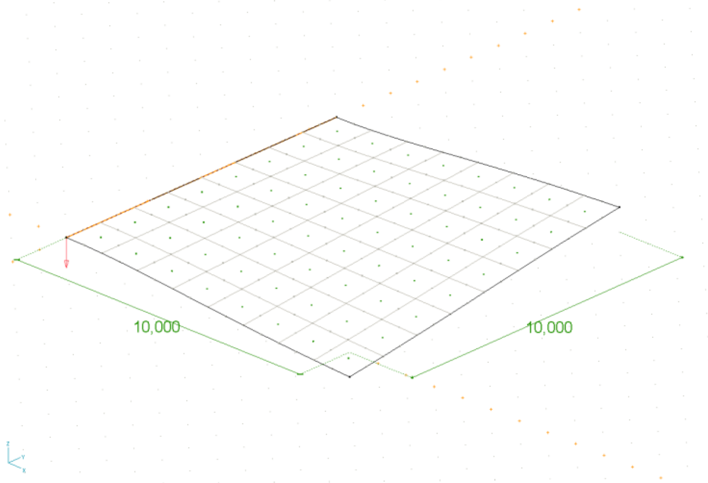
Comparison with NAFEMS example

Mode	NAFEMS (Hz)	AxisVM (Hz)	%
1	7,94	8,02	1,01
2	12,84	13,02	1,40
3	17,94	18,41	2,62
4	19,13	19,33	1,05
5	24,01	24,62	2,54
6	27,92	28,24	1,15

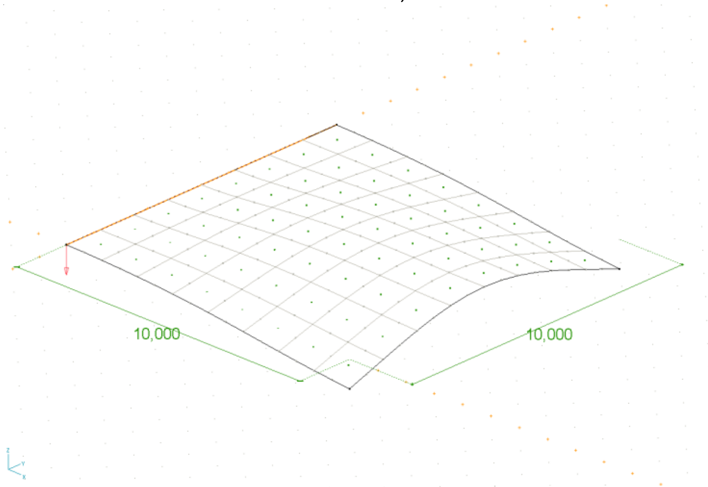
Software Release Number: X5r1
Date: 07. 11. 2018.
Tested by: InterCAD
File name: dynam3.axs

Thema	Cantilevered thin square plate.
Analysis Type	Vibration analysis.
Geometry	 Top view (thickness = 5,0 cm)
Loads	Self-weight
Boundary Conditions	eX = eY = eZ = fiX = fiY = fiZ = 0 along y-axis
Material Properties	$E = 20000\ kN / cm^2$ $\nu = 0,3$ $\rho = 8000\ kg / m^3$
Element types	Parabolic quadrilateral shell element (heterosis type).
Mesh	

Target	First 5 mode shapes
Results	 Mode 1: f = 0,42 Hz  Mode 3: f = 2,53 Hz  Mode 5: f = 3,68 Hz



Mode 2: f = 1,02 Hz

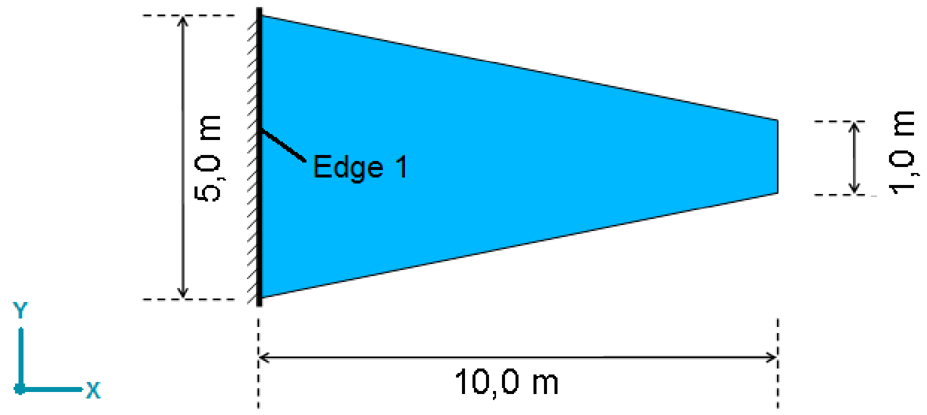
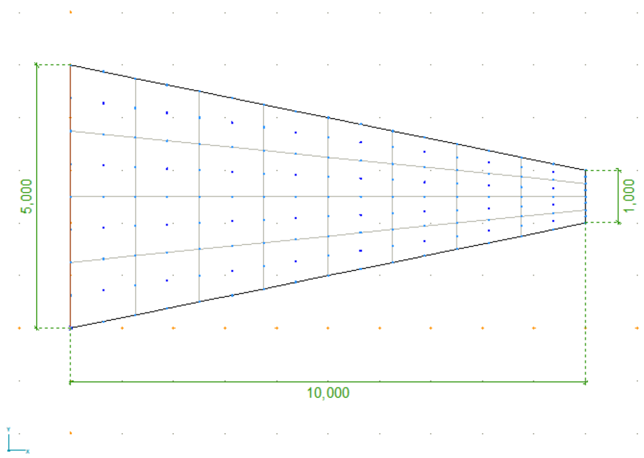


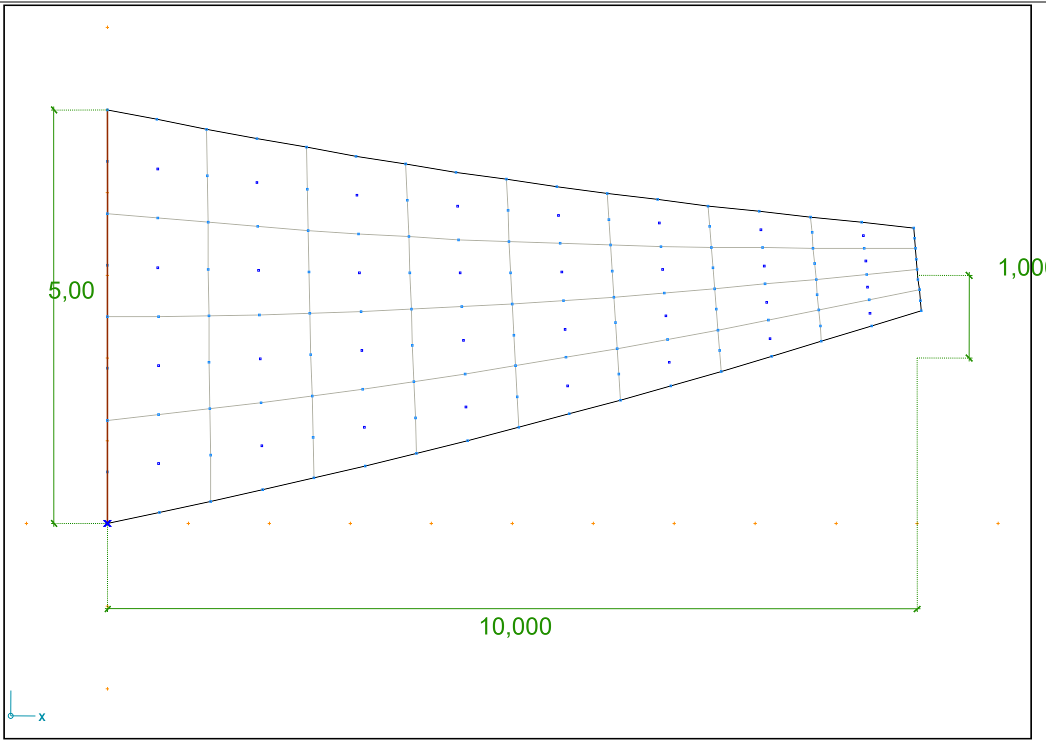
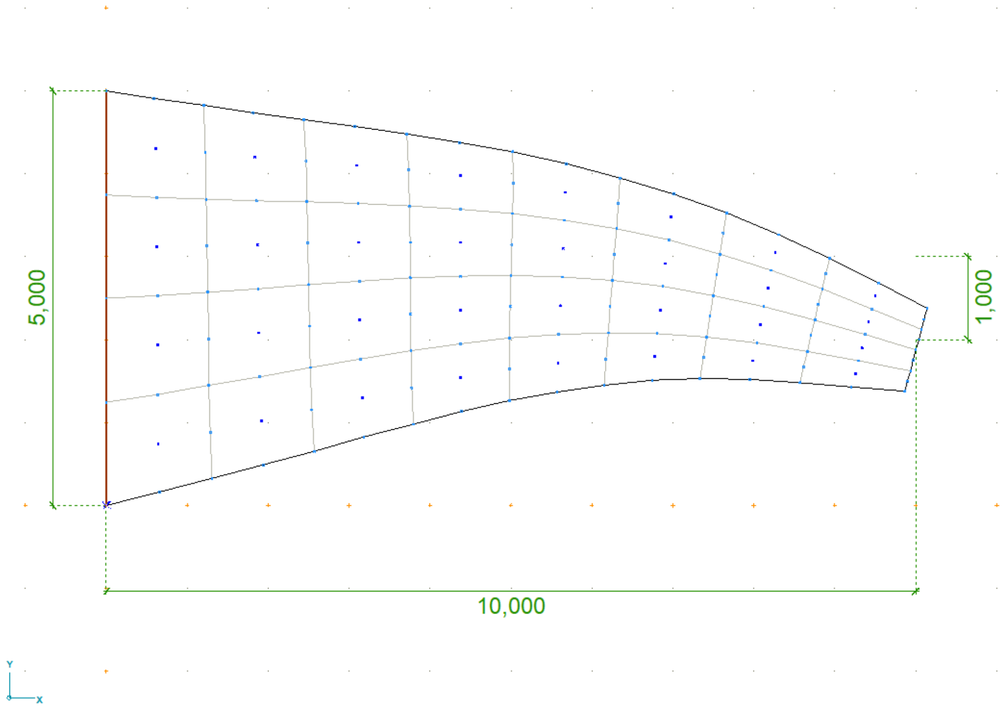
Mode 4: f = 3,22 Hz

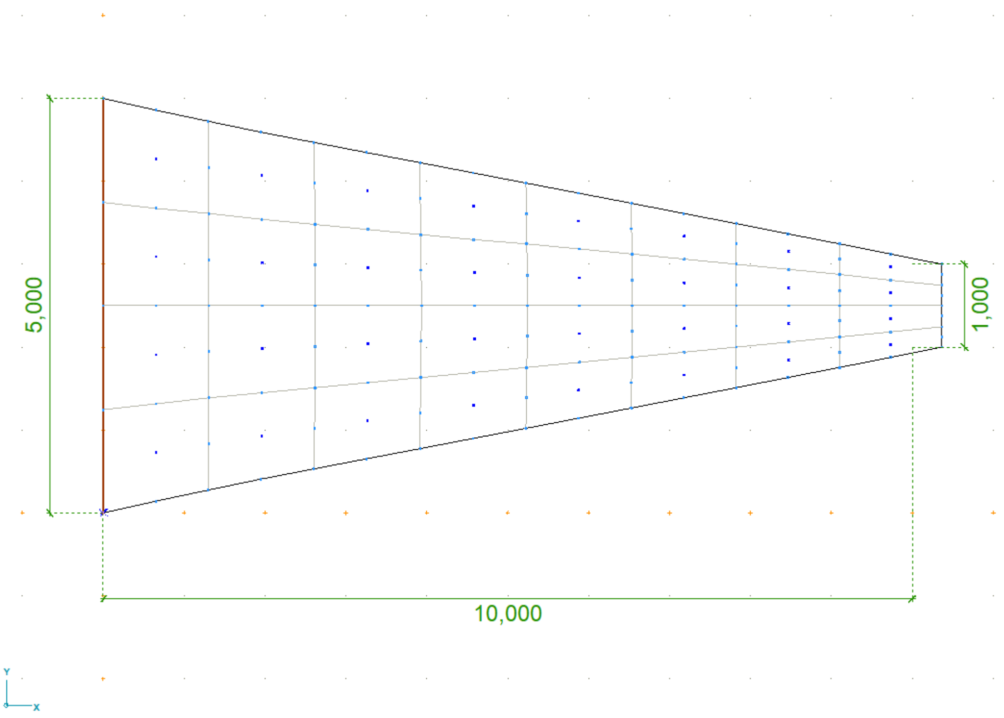
Comparison with NAFEMS example

Mode	NAFEMS (Hz)	AxisVM (Hz)	%
1	0,421	0,420	-0,24
2	1,029	1,020	-0,87
3	2,580	2,530	-1,94
4	3,310	3,220	-2,72
5	3,750	3,680	-1,87

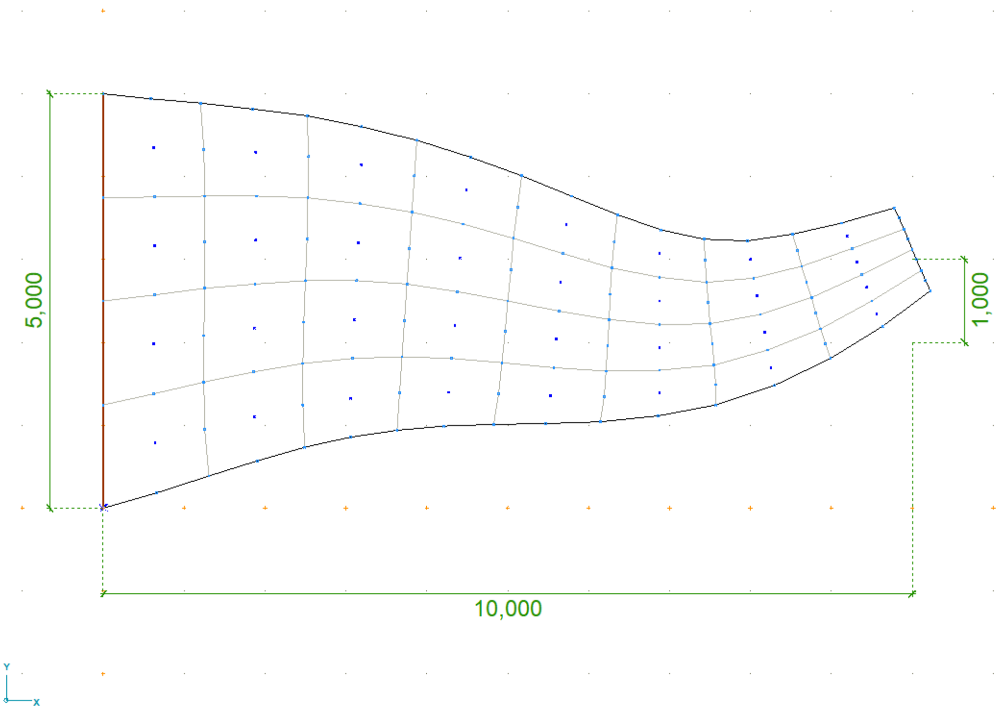
Software Release Number: X5r1
Date: 07. 11. 2018.
Tested by: InterCAD
File name: dynam4.axs

Thema	Cantilevered tapered membrane.
Analysis Type	Vibration analysis.
Geometry	Side view (thickness = 10,0 cm)
Loads	Self-weight
Boundary Conditions	Edge 1: Nodal DOF: Fixed node Other nodes: DOF: (f f C C C C) (f: free; C: constrained)
Material Properties	$E = 20000$ kN / cm^2 $\nu = 0,3$ $\rho = 8000$ kg / m^3
Element types	Parabolic quadrilateral membrane (plane stress)
Mesh	

Target	First 4 mode shapes
Results	 Mode 1: f = 44,50 Hz  Mode 2: f = 128,60 Hz



Mode 3: f = 162,48 Hz



Mode 4: f = 241,46 Hz

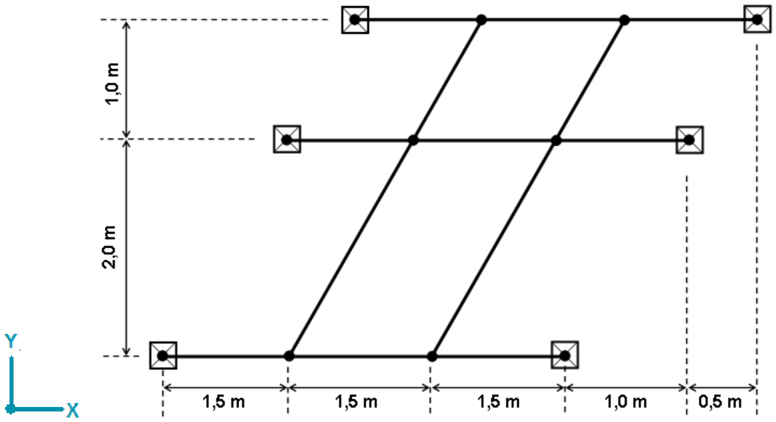
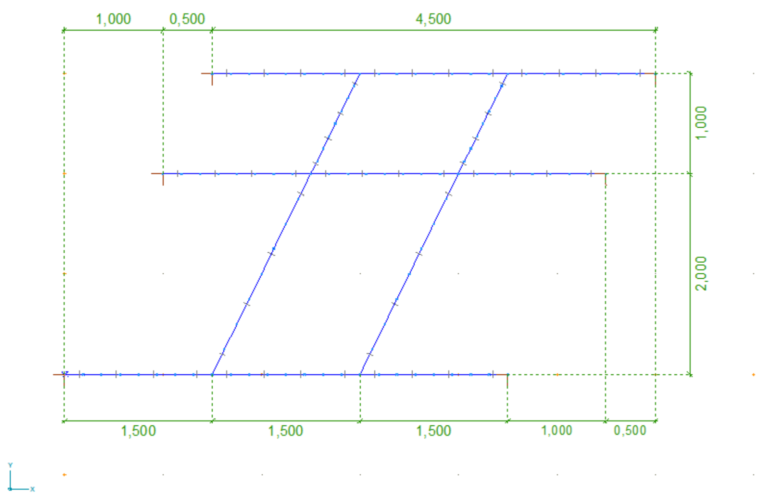
Results

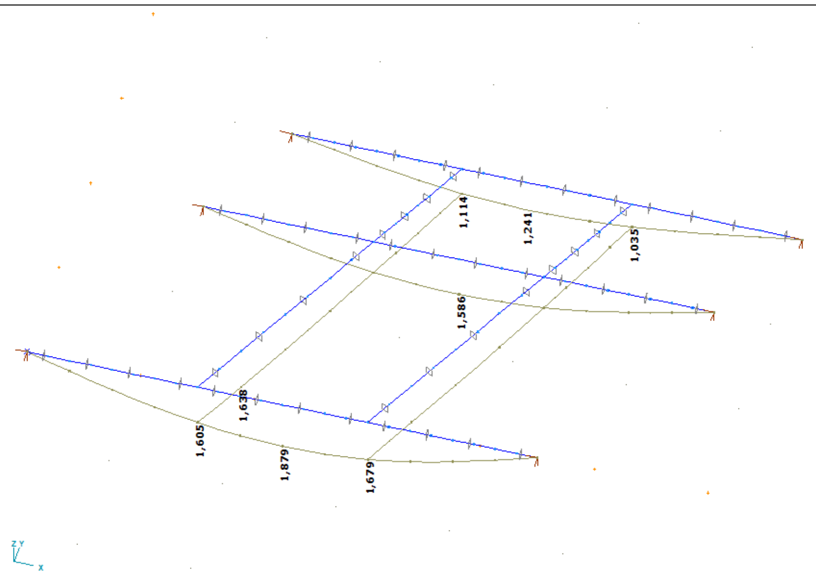
Comparison with NAFEMS example

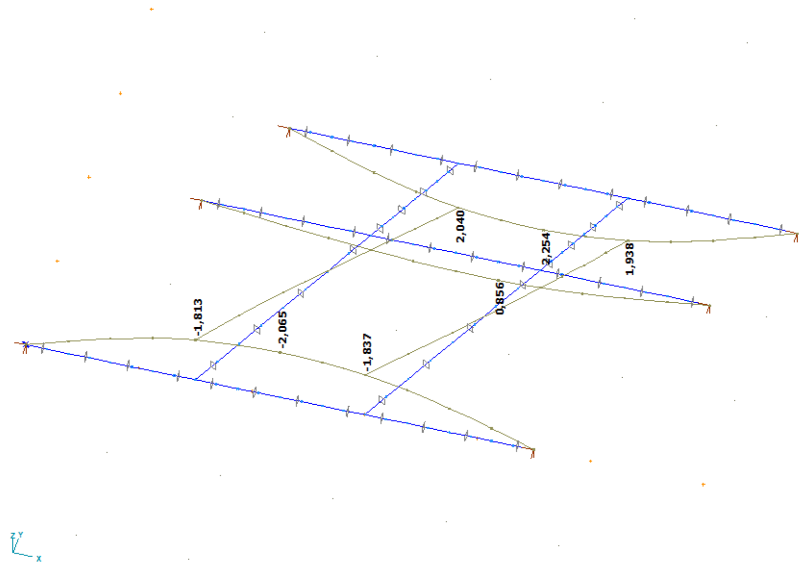
Mode	NAFEMS (Hz)	AxisVM (Hz)	%
1	44,62	44,50	-0,27
2	130,03	128,60	-1,10
3	162,70	162,48	-0,14
4	246,05	241,46	-1,87

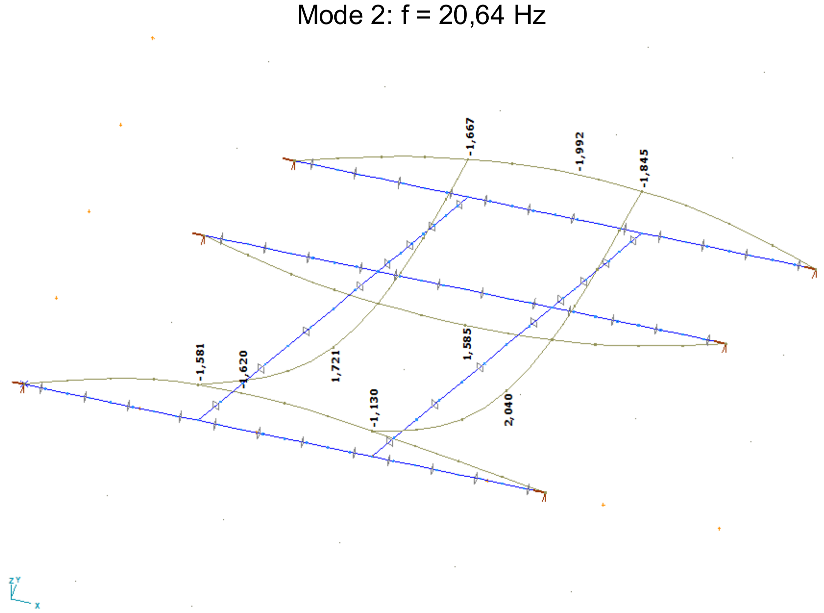
Software Release Number: R3
Software Release Number: X4r1

Date: 07. 11. 2018.
Tested by: InterCAD
File name: dynam5.axs

Thema	Flat grillages.
Analysis Type	Vibration analysis.
Geometry	 Top view
Loads	Self-weight
Boundary Conditions	eX = eY = eZ = 0 at the ends (simple supported beams) Nodal DOF: Grillage in X-Y plane
Material Properties	E = 20000 kN / cm^2 G = 7690 kN / cm^2 ν = 0,3 ρ = 7860 kg / m^3
Cross Section	A = 0,004 m^2 Ix = 2,5E-5 m^4 Iy = Iz = 1,25E-5 m^4
Element types	Rib element: Three node beam element (shear deformation is taken into account)
Mesh	

<table>
<tr><td>Target</td><td>First 3 mode shapes</td></tr>
<tr><td>Results</td><td>


Mode 1: f = 16,90 Hz


Mode 2: f = 20,64 Hz


Mode 3: f = 51,76 Hz
</td></tr>
<tr><td></td><td></td></tr>
</table>

Mode	Reference	AxisVM (Hz)	%
1	16,85	16,90	0,30
2	20,21	20,64	2,13
3	53,30	51,76	-2,89

Reference:

C.T.F. ROSS: Finite Element Methods In Engineering Science

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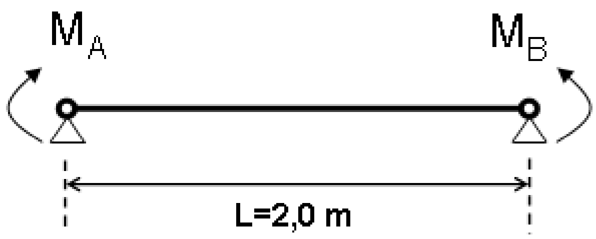
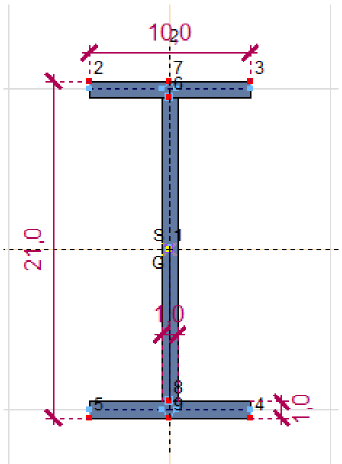
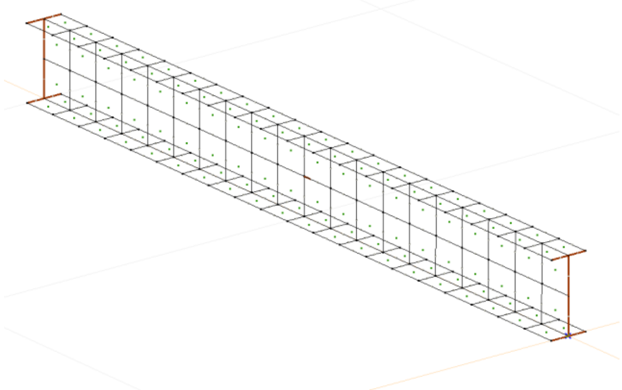
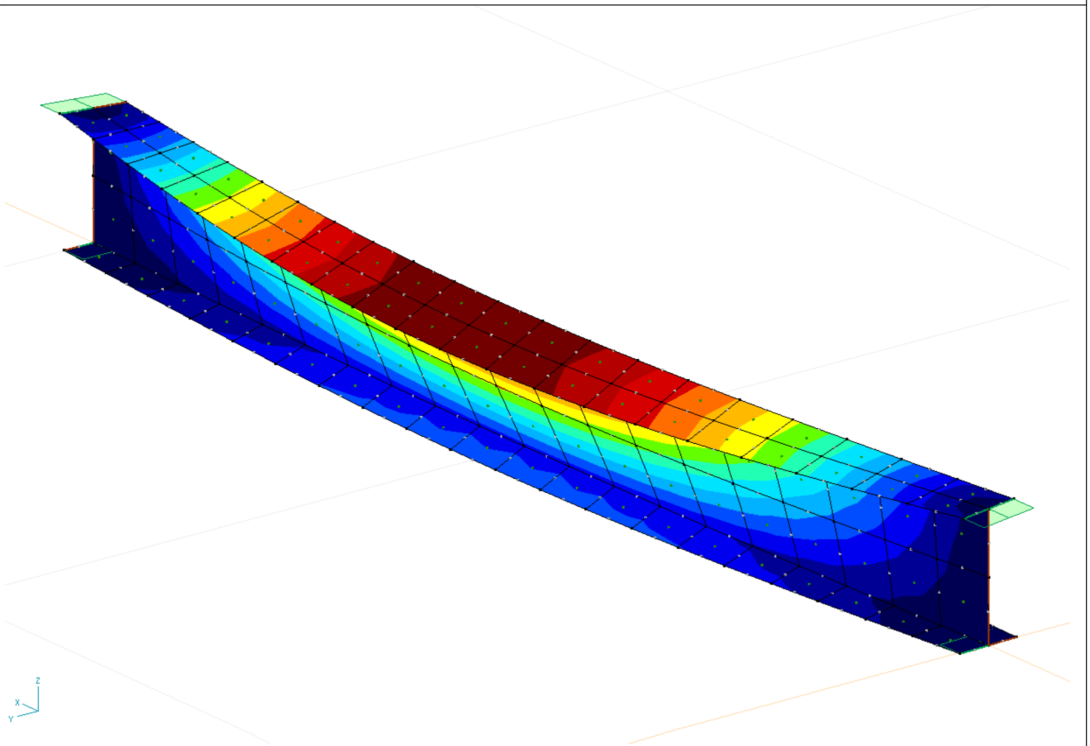
Stability

Date: 08. 11. 2018.
Tested by: InterCAD
File name: buckling1.axs

Thema	Simply supported beam.
Analysis Type	Buckling analysis.
Geometry	 Front view  Cross section(I_z =168,3 cm^4, I_t =12,18 cm^4, I_w =16667 cm^6)
Loads	Bending moment at both ends of beam M_A = 1,0 kNm, M_B = -1,0 kNm (Moments are applied as surface edge loads)
Boundary Conditions	eX = eY = eZ = 0 at A eX = eY = eZ = 0 at B k_z = k_w = 1
Material Properties	E = 20600 kN / cm^2 ν = 0,3
Element types	Parabolic quadrilateral shell element (heterosis type)
Mesh	

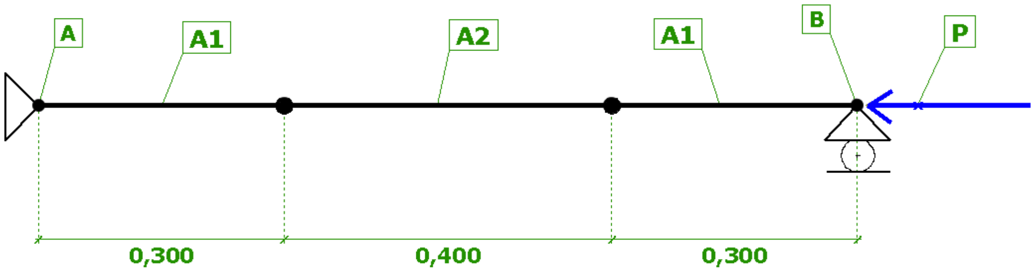
Target	M_{cr} = ? (for lateral torsional buckling)
Results	 Analytical solution $$M_{cr} = \frac{\pi^2 \cdot E \cdot I_Z}{L^2}\sqrt{\frac{I_W}{I_Z} + \frac{L^2 \cdot G \cdot I_t}{\pi^2 \cdot E \cdot I_Z}}$$ $$M_{cr} = \frac{\pi^2 \cdot 20600 \cdot 168{,}3}{200^2}\sqrt{\frac{16667}{168{,}3} + \frac{200^2 \cdot 7923 \cdot 12{,}18}{\pi^2 \cdot 20600 \cdot 168{,}3}} = 12451 \quad kNcm = 124{,}51 \quad kNm$$ AxisVM result M_{cr} = 125,3 kNm Difference +0,6%

Software Release Number: X5r1
Date: 07. 11. 2018.
Tested by: InterCAD
File name: buckling2.axs

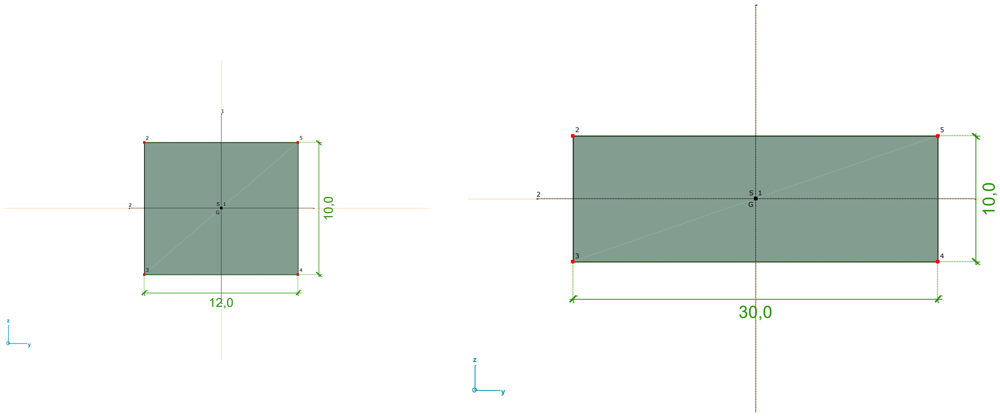
Thema
Simply supported beam.

Analysis Type
Buckling analysis.

Geometry



Front view (L = 1,0 m)



Section A_1 Section A_2

Cross-sections

Loads
P = -1,0 kN at point B.

Boundary Conditions
eX = eY = eZ = 0 at A
eY = eZ = 0 at B

Material Properties
$E = 20000\ kN / cm^2$
$\nu = 0,3$

Element types
Beam element

Target
P_{cr} = ? (for inplane buckling)

Results

	Theory	AxisVM	e [%]
P_{cr} [kN]	3,340	3,337	-0,09

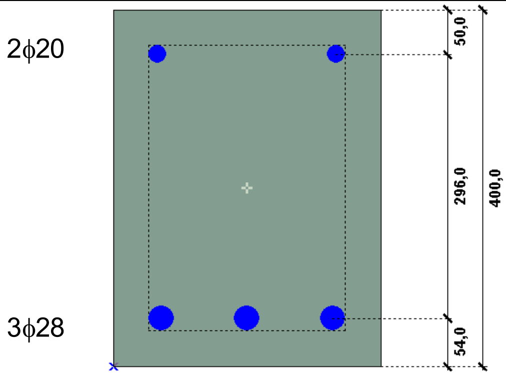
Design

Date: 08. 11. 2018.
Tested by: InterCAD
File name: RC column1.axs

Thema
N-M interaction curve of cross-section (EN 1992-1-1:2004).

Analysis Type
Linear static analysis+design.

Geometry



Section: 300x400 mm
Covering: 40 mm

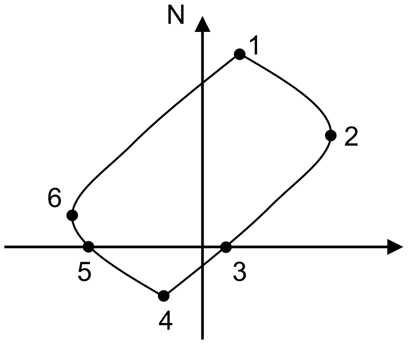
Loads
Arbitrary.

Boundary Conditions
Arbitrary.

Material Properties
Concrete:
f_{cd}=14,2 N/mm^2
e_{c1}=0,002 e_{cu}=0,0035 (parabola-constans σ-ε diagram)
Steel:
f_{sd}=348 N/mm^2
e_{su}=0,015

Target
Compare the program results with with hand calculation at keypoints of M-N interaction curve.

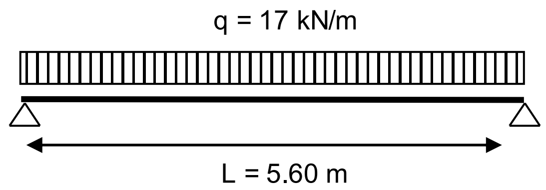
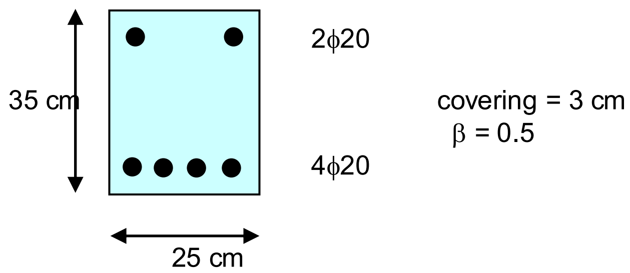
Results

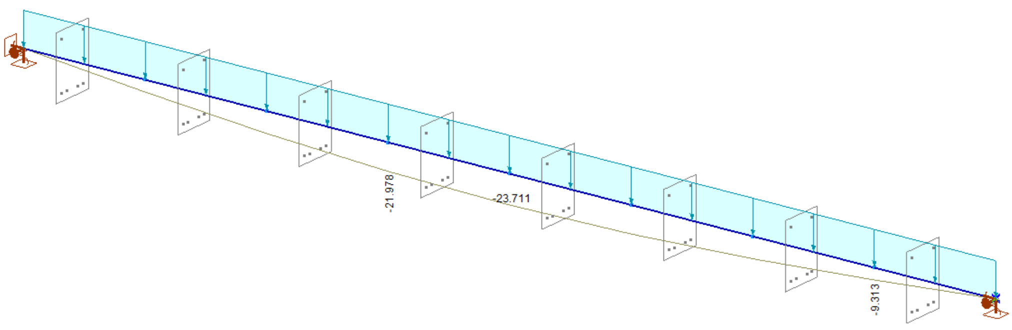


	N [kN]	M [kNm]	N AxisVM	M(N) AxisVM	e %
1	-2561	+61	-2566,5	+61,4	+0,7
2	-1221	+211	-1200	+209,7	-0,6
3	0	+70		+70,5	+0,7
4	+861	-61	866,5	-61,4	+0,7
5	0	-190		-191,2	+0,6
6	-362	-211	-350	-209,7	-0,6

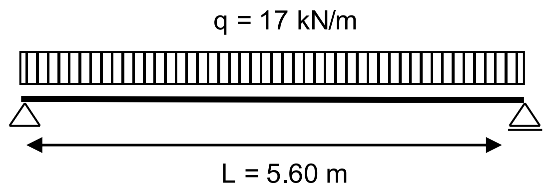
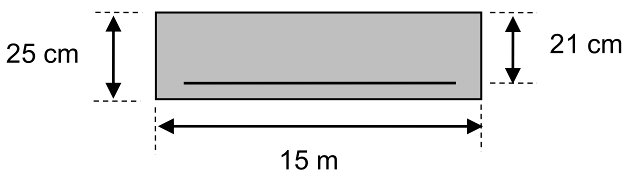
Reference: Dr. Kollár L. P., Vasbetonszerkezetek I. Műegyetemi kiadó

Software Release Number: X5r1
Date: 08. 11. 2018.
Tested by: InterCAD
File name: RCbeam.axs

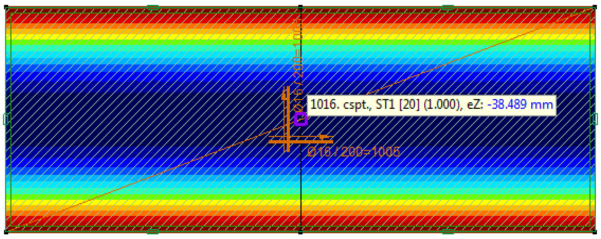
Thema	RC beam deflection according to EC2, EN 1992-1-1:2010.
Analysis Type	Materially nonlinear analysis.
Geometry	 Side view  Section
Loads	q = 17 kN /m distributed load
Boundary Conditions	Simply supported beam.
Material Properties	Concrete: C25/30, $\varphi = 2.1$ Steel: B500B ε=0.4‰ shrinkage strain
Element types	Simple 12DOF beam elements (Euler-Bernoulli beam)
Target	$e_{z,\ max}$

Results without shrinkage	 Diagram e_z <u>Hand calculation by integration of κ diagram:</u> $\kappa = \zeta \cdot \kappa_{II} + (1-\zeta)\cdot\kappa_{I} \qquad \zeta = 1-\beta\cdot\left(\frac{M_{cr}}{M}\right)^2$ $e = 19.33\,mm$ where, κ_I is the curvature which was calculated based on uncracked section κ_{II} is the curvature which was calculated based on cracked section <u>Calculation with AxisVM:</u> e = 19.7 mm (difference ~ 2%)
Results with shrinkage	<u>Hand calculation by integration of κ diagram:</u> $\kappa = \zeta \cdot \kappa_{II} + (1-\zeta)\cdot\kappa_{I} \qquad \zeta = 1-\beta\cdot\left(\frac{M_{cr}}{M}\right)^2$ $e = 23.02\,mm$ where, κ_I is the curvature which was calculated based on uncracked section κ_{II} is the curvature which was calculated based on cracked section <u>Calculation with AxisVM:</u> e = 23.7 mm (difference ~ 3%)

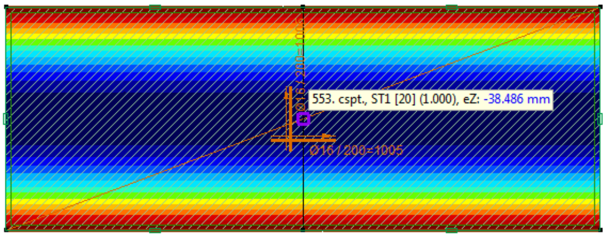
Software Release Number: X5r1
Date: 08. 11. 2018.
Tested by: InterCAD
File name: RC_Slab_1.axs

Thema	RC one-way slab deflection according to EC2, EN 1992-1-1:2010.
Analysis Type	Materially nonlinear analysis.
Geometry	 Side view Section:  As = ϕ16/200 β = 0.5
Loads	q = 17 kN /m distributed load
Boundary Conditions	Simply supported one-way slab.
Material Properties	Concrete: C25/30, φ = 2.1, ν = 0.0 Steel: B500B ε=0.4‰ shrinkage strain
Element types	triangle shell elements
Target	$e_{z,\ max}$

<table>
<tr>
<td>Results - without shrinkage</td>
<td>



NL behaviour in ε-N + κ-M



NL behaviour in κ-M only

Diagram e_z

<u>Hand calculation by integration of κ diagram:</u>

$$\kappa = \zeta \cdot \kappa_{II} + (1-\zeta)\cdot \kappa_I \qquad \zeta = 1 - \beta \cdot \left(\frac{M_{cr}}{M}\right)^2$$

$$e = 37.43 mm$$

where,

κ_I is the curvature which was calculated based on uncracked section
κ_{II} is the curvature which was calculated based on cracked section

<u>Calculation with AxisVM:</u>

e = 38.49 mm (NL ε-N + κ-M) (difference ~ +3%)
e = 38.49 mm (NL κ-M) (difference ~ +3%)

</td>
</tr>
<tr>
<td>Results - with shrinkage</td>
<td>

<u>Hand calculation by integration of κ diagram:</u>

$$\kappa = \zeta \cdot \kappa_{II} + (1-\zeta)\cdot \kappa_I \qquad \zeta = 1 - \beta \cdot \left(\frac{M_{cr}}{M}\right)^2$$

$$e = 44.43 mm$$

where,

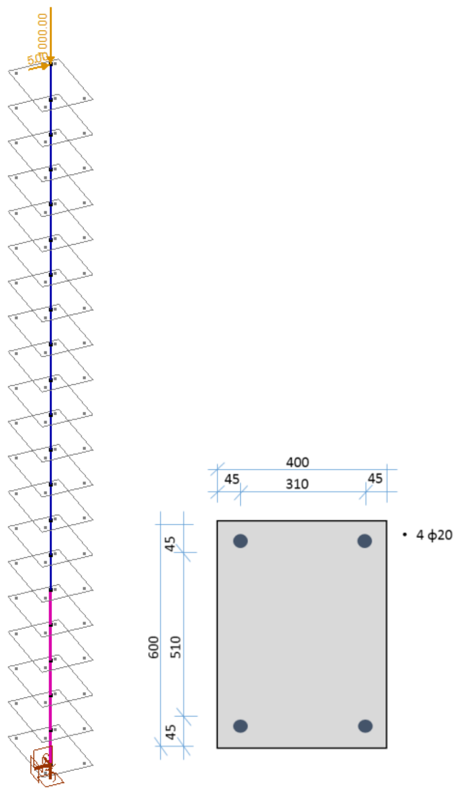
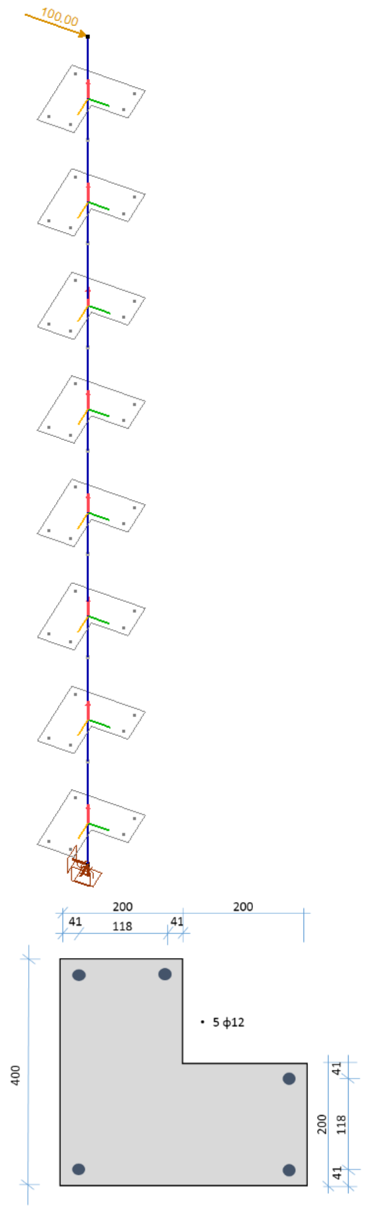
κ_I is the curvature which was calculated based on uncracked section
κ_{II} is the curvature which was calculated based on cracked section

<u>Calculation with AxisVM:</u>

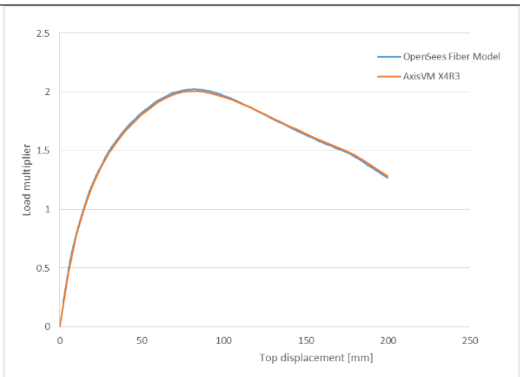
e = 46.91 mm (NL ε-N + κ-M) (difference ~ +5%)
e = 46.79 mm (NL κ-M) (difference ~ +5%)

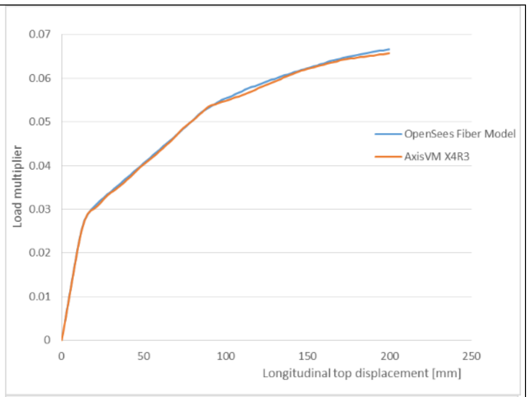
</td>
</tr>
</table>

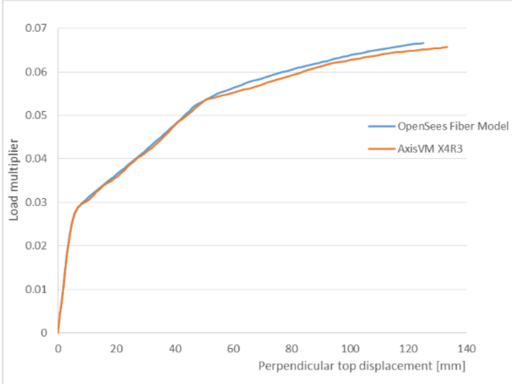
Software Release Number: X5r31
Date: 08. 11. 2018.
Tested by: InterCAD
File name: RCcolumn.axs. RCLcolumn.axs

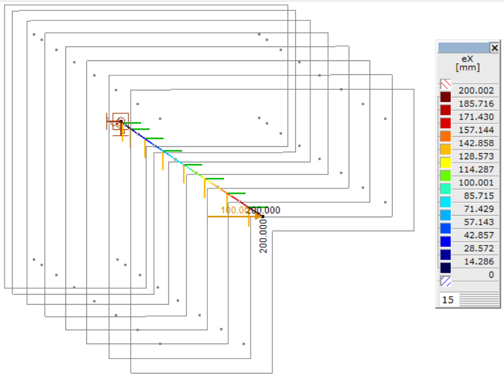
Thema	Nonlinear analysis of RC columns according to EC2, EN 1992-1-1:2010.
Analysis Type	Materially and geometrically nonlinear analysis.
Geometry	 
Loads	Concentrated force on the top
Boundary Conditions	Cantilever
Material Properties	Concrete: C25/30, $\varphi = 2,0$ Steel: B500B
Element types	Simple 12DOF beam elements (Euler-Bernoulli beam)
Target	$e_{z,\ max}$

Results

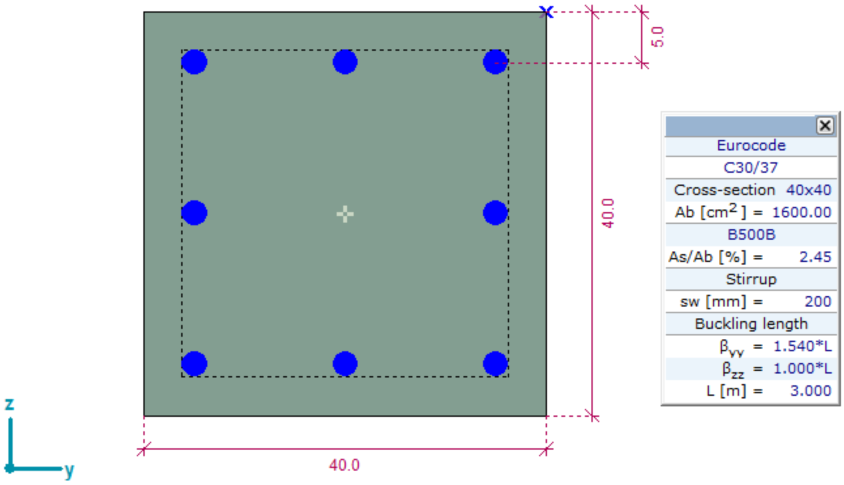

OpenSees Fiber Model
AxisVM X4R3
Load multiplier
Top displacement [mm]
0
0.5
1
1.5
2
2.5
0
50
100
150
200
250

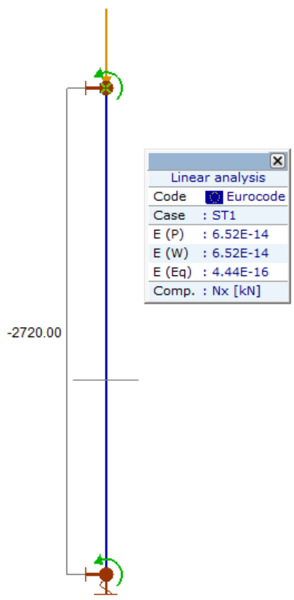

OpenSees Fiber Model
AxisVM X4R3
Load multiplier
Longitudinal top displacement [mm]
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0
50
100
150
200
250

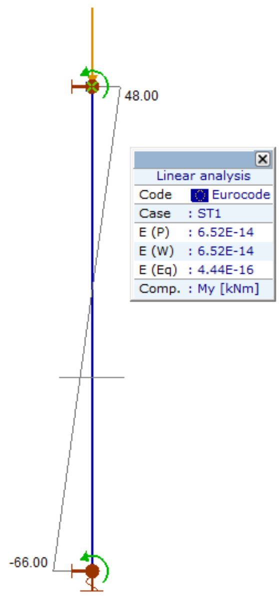

OpenSees Fiber Model
AxisVM X4R3
Load multiplier
Perpendicular top displacement [mm]
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0
20
40
60
80
100
120
140


eX
[mm]
200.002
185.716
171.430
157.144
142.858
128.573
114.287
100.001
85.715
71.429
57.143
42.857
28.572
14.286
0
15
200.000

Software Release Number: X5r1
Date: 08. 11. 2018.
Tested by: InterCAD
File name: RCcolumn2.axs

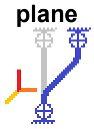
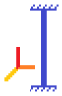
<table>
<tr><td>Thema</td><td>Axially loaded RC column check according to EC2, EN 1992-1-1:2010.</td></tr>
<tr><td>Analysis Type</td><td>Materially and geometrically linear analysis.</td></tr>
<tr><td>Geometry</td><td>




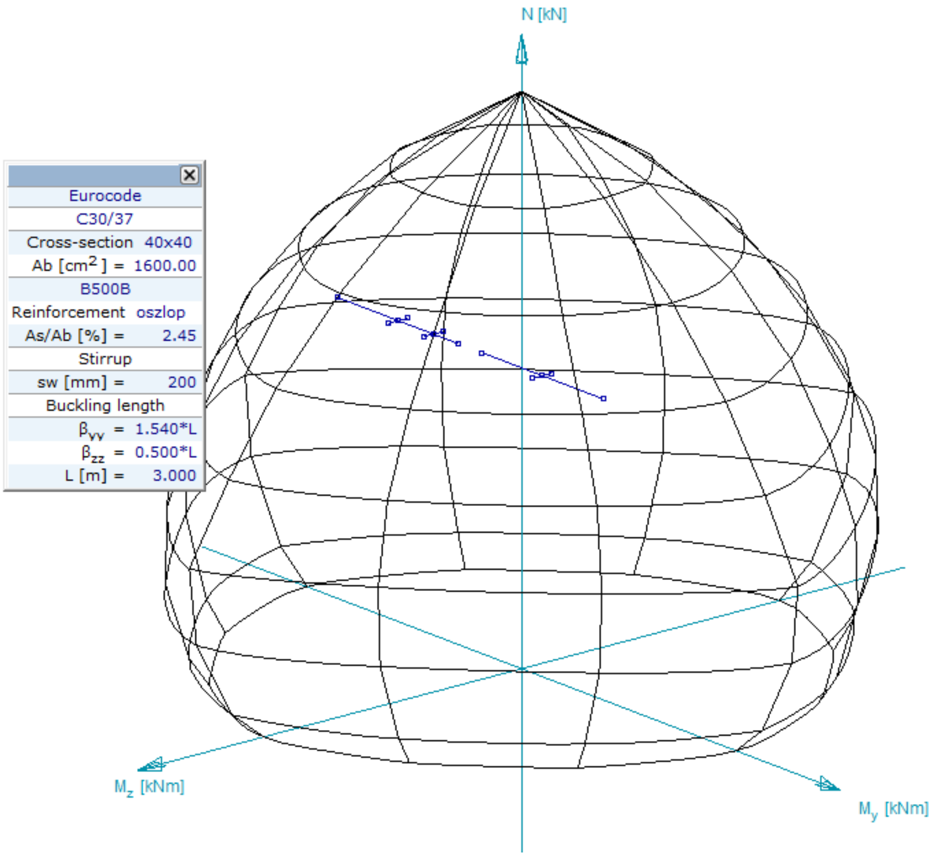


</td></tr>
<tr><td>Loads</td><td>Concentrated force N_{Ed} = 2720 kN
Bending moments:
at the top M_{yEd} = 48 kNm
at the bottom M_{yEd} = 66 kNm</td></tr>
<tr><td>Material Properties</td><td>Concrete: C30/37, φ = 2,0
Steel: B500B</td></tr>
<tr><td>Element types</td><td>Simple 12DOF beam elements (Euler-Bernoulli beam)</td></tr>
<tr><td>Target</td><td>Calculate eccentricities according to EN 1992-1</td></tr>
</table>

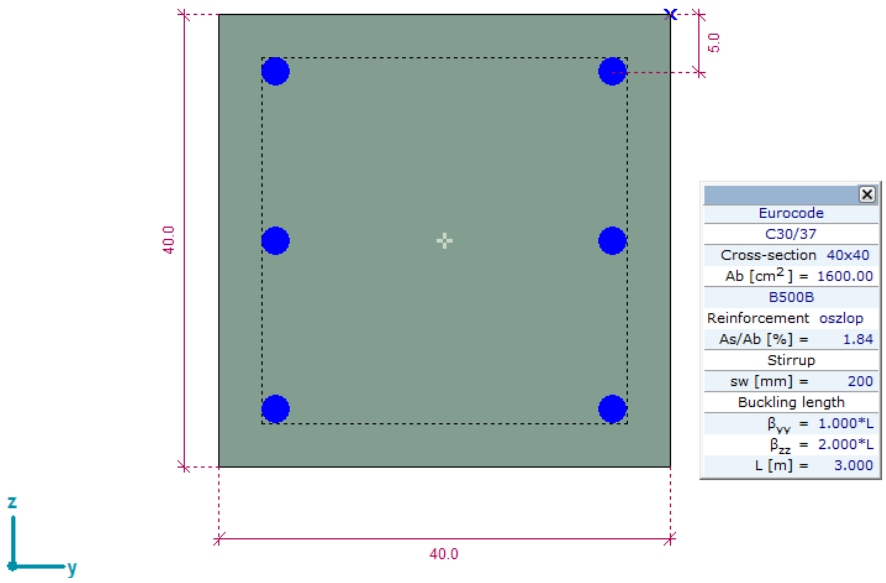
Results

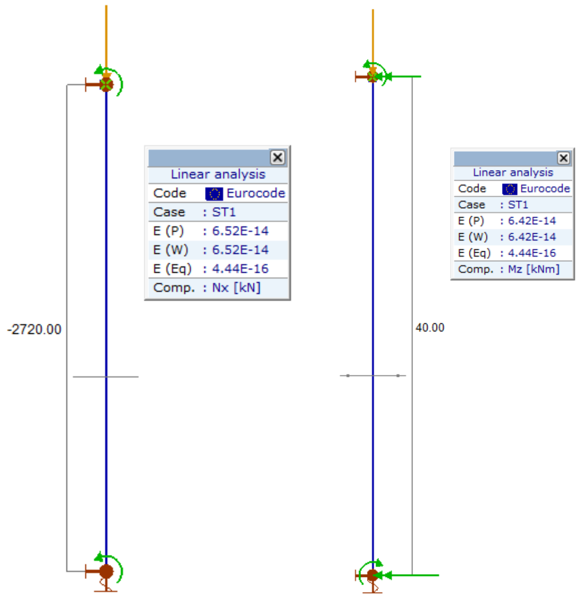
[cm]		Hand calculation				AxisVM				
		e_0	e_i	e_2	**e_{tot}**	e_0	e_i	e_2	**e_{tot}**	e %
x-z plane 	Bottom	2.43	1.16	2.73	**6.31**	2.43	1.16	2.73	**6.31**	0
	Middle	0.97	0**	0**	**2***	0.97	0**	0**	**2***	0
	Top	1.76	1.16	2.73	**5.65**	1.76	1.16	2.73	**5.65**	0
x-y plane 	Bottom	0	0.38	0.36	**2***	0	0.38	0.36	**2***	0
	Middle	0	0.38	0.36	**2***	0	0.38	0.36	**2***	0
	Top	0	0.38	0.36	**2***	0	0.38	0.36	**2***	0

* due to minimal eccentricity requirement
** due to the buckling



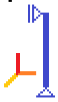
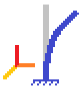
Software Release Number: X5r1
Date: 08. 11. 2018.
Tested by: InterCAD
File name: Rccolumn3.axs

<table>
<tr><td>Thema</td><td>Axially loaded RC column check according to EC2, EN 1992-1-1:2010.</td></tr>
<tr><td>Analysis Type</td><td>Materially and geometrically linear analysis.</td></tr>
<tr><td>Geometry</td><td>


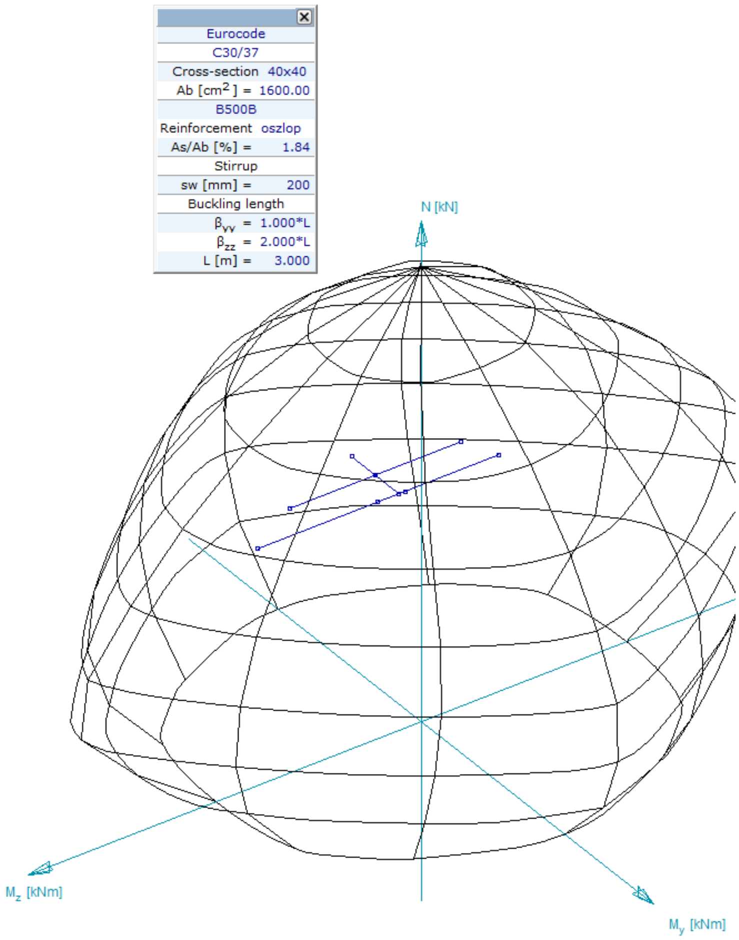


</td></tr>
<tr><td>Loads</td><td>Concentrated force N_{Ed} = 2720 kN
Bending moments:
at the top M_{zEd} = 40 kNm
at the bottom M_{zEd} = 40 kNm</td></tr>
<tr><td>Material Properties</td><td>Concrete: C30/37, φ = 2,0
Steel: B500B</td></tr>
<tr><td>Element types</td><td>Simple 12DOF beam elements (Euler-Bernoulli beam)</td></tr>
<tr><td>Target</td><td>Calculate eccentricities according to MSZ EN 1992-1</td></tr>
</table>

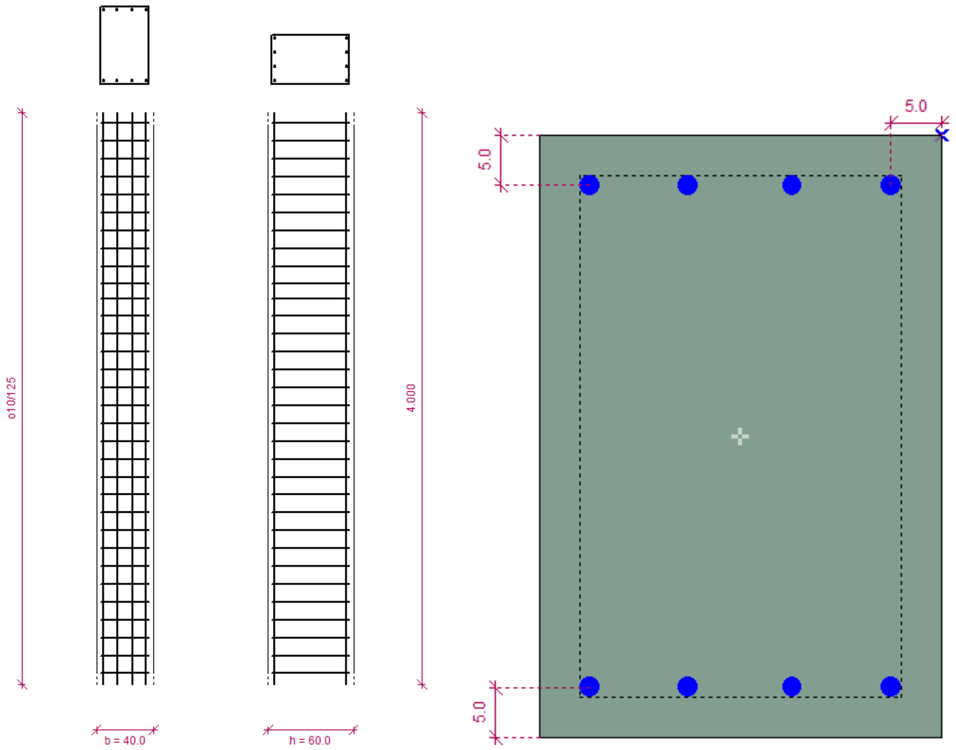
Results

[cm]		Hand calculation				AxisVM				
		e_0	e_i	e_2	**e_{tot}**	e_0	e_i	e_2	**e_{tot}**	e %
x-z plane 	Bottom	0	0.75	0**	**2***	0	0.75	0**	**2***	0
	Middle	0	0.75	1.21	**2***	0	0.75	1.21	**2***	0
	Top	0	0.75	0**	**2***	0	0.75	0**	**2***	0
x-y plane 	Bottom	1.47	1.5	4.35	**7.32**	1.47	1.5	4.35	**7.32**	0
	Middle	1.47	0.75 **	3.07 **	**5.29**	1.47	0.75 **	3.08 **	**5.3**	~0
	Top	1.47	0**	0**	**2***	1.47	0**	0**	**2***	0

* due to minimal eccentricity requirement
** due to the buckling

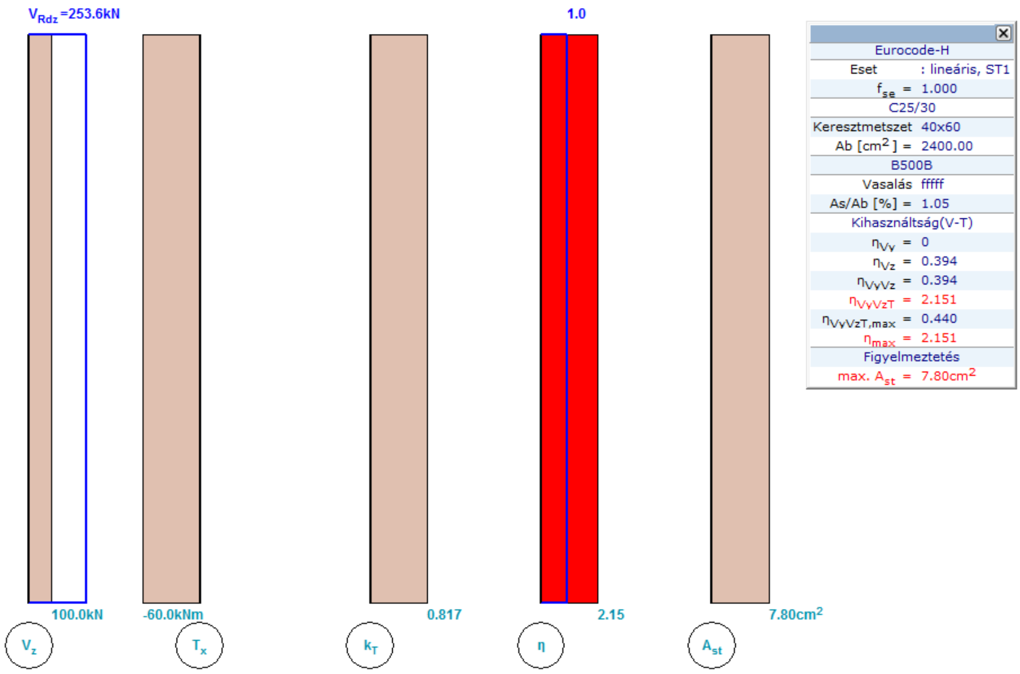


Software Release Number: X5r1
Date: 09. 11. 2018.
Tested by: InterCAD
File name: RCcolumnVT.axs

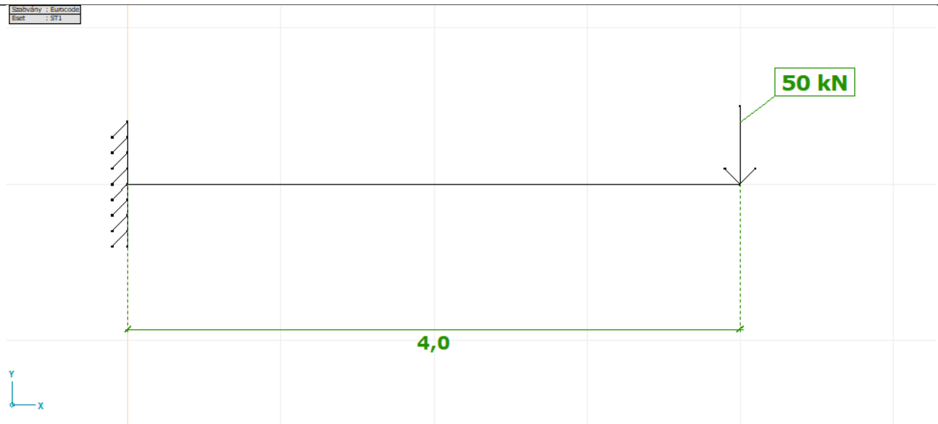
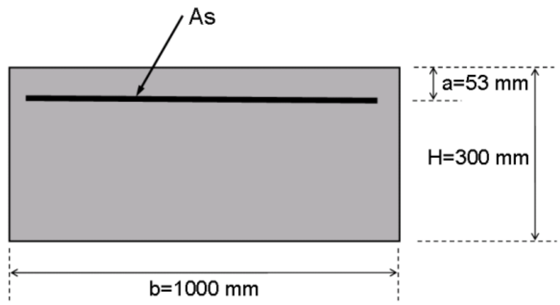
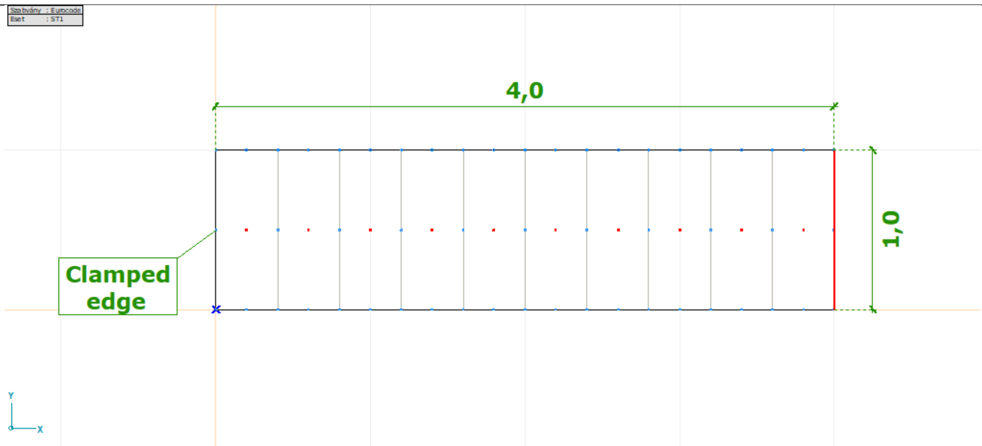
Thema	Shear and torsion check of RC column according to EC2, EN 1992-1-1:2010.
Analysis Type	Materially and geometrically linear analysis.
Geometry	
Loads	N_{Ed} = 1000 kN V_{zEd}= 100 kN T_{xEd}=60 kNm
Properties	Concrete: C25/30 Steel: B500B A_{s1} = A_{s2} = 4 Φ16 A_{sw} = Φ10/125 c = 30 mm θ = 45°
Element types	Simple 12DOF beam elements (Euler-Bernoulli beam)
Target	Shear and torsion check

Results

		Hand calculation	AxisVM	ε %
x-z plane	$V_{Rd,c}$ [kN]	209.7	209.7	0
	$V_{Rd,s}$ [kN]	253.3	253.6	<1
	$V_{Rd,max}$ [kN]	1010	1011	<1
	$T_{Rd,c}$ [kNm]	38.6	38.6	0
	$T_{Rd,max}$ [kNm]	175.7	175.7	0
	k_T [-]	0.817	0.817	0
	A_{st} [mm^2]	780	780	0



Software Release Number: X5r1
Date: 07. 11. 2018.
Tested by: InterCAD
File name: beam2.axs

Thema	Required steel reinforcement of RC plate according to EC2, EN 1992-1-1:2004.
Analysis Type	Linear analysis.
Geometry	 Side view  Cross-section
Loads	Pz = -50 kN point load
Boundary Conditions	Clamped cantilever plate. Fix line support on clamped edge. Nodal DOF: Plate in X-Y plane
Material Properties	Concrete: C25/30 Steel: B500A
Element types	Parabolic quadrilateral plate element (heterosis type)
Mesh	 Top view

Target	AXT steel reinforcement along x direction at the top of the support

Results

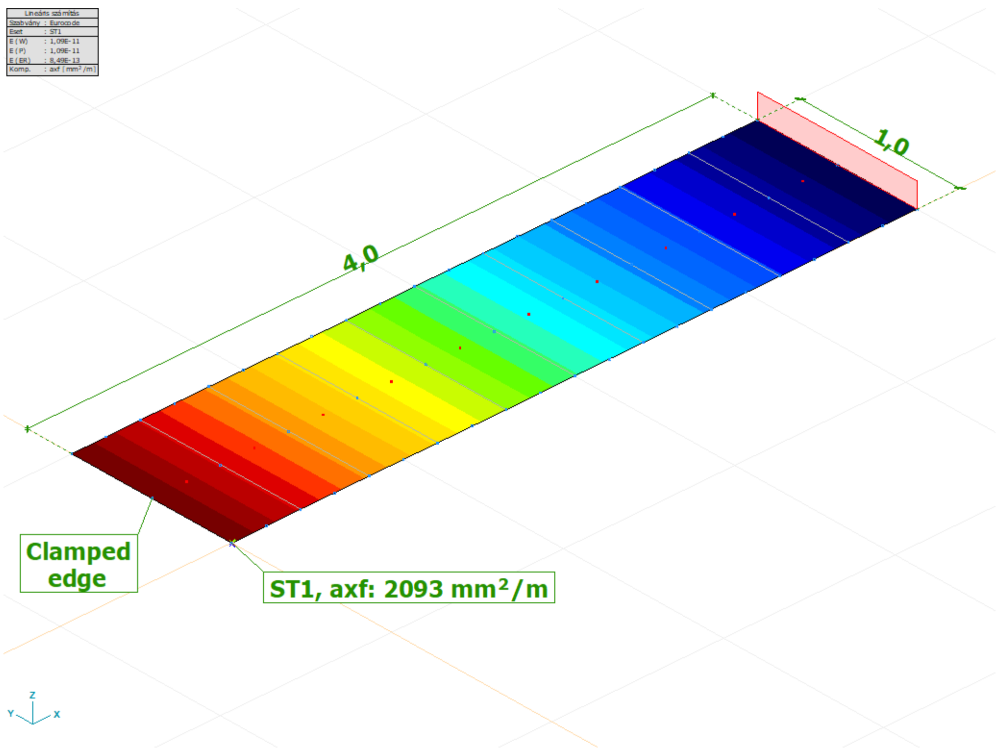


Diagram AXT

Calculation according to EC2:

$$f_{cd} = \frac{25}{1{,}5} = 16{,}6 \ N/mm^2 \qquad f_{yd} = \frac{500}{1{,}15} = 435 \ N/mm^2$$

$$\xi_{c0} = \frac{c \cdot \varepsilon_{cu} \cdot E_S}{\varepsilon_{cu} \cdot E_S + f_{yd}} = \frac{0{,}85 \cdot 0{,}0035 \cdot 20000}{0{,}0035 \cdot 20000 + 435} = 0{,}54$$

d = 300 – 53 = 247 mm

$$M_{sd} = M_{Rd} = b \cdot x_c \cdot f_{cd} \left(d - \frac{x_c}{2} \right) = 200 \ kNm \qquad x_c = \begin{Bmatrix} 439 > h \\ 55 \end{Bmatrix}$$

$$\xi_c = \frac{x_c}{d} = \frac{55}{247} = 0{,}22 < \xi_{c0} = 0{,}54$$ Steel reinforcement is yielding

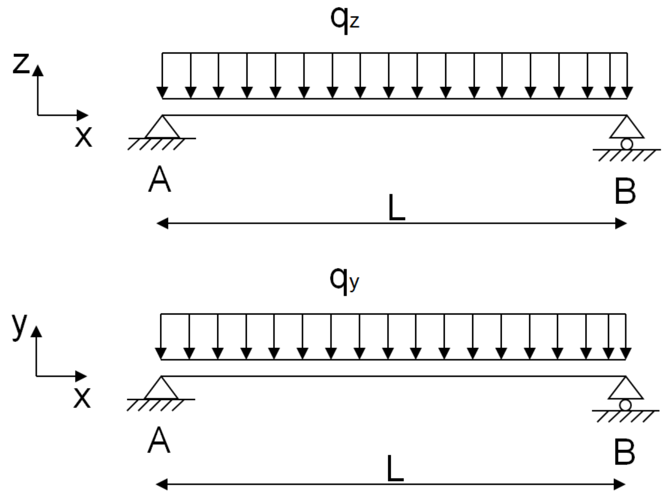
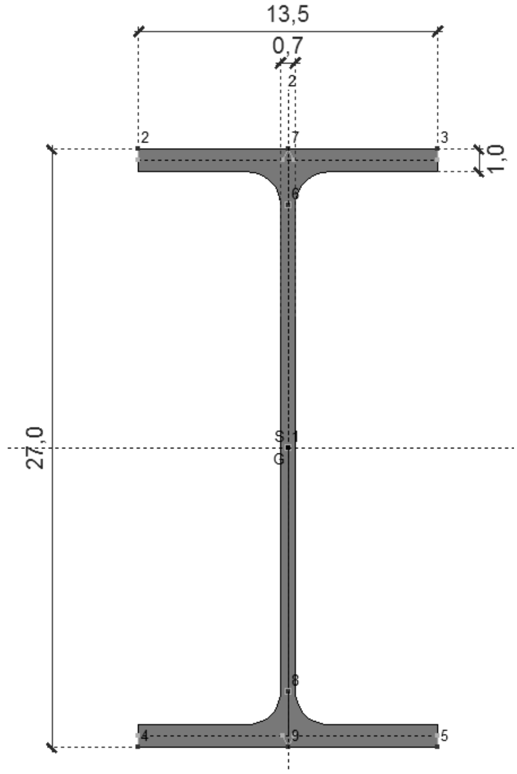
$$A_S = \frac{b \cdot x_c \cdot f_{cd}}{f_{yd}} = \frac{55 \cdot 1000 \cdot 16{,}6}{435} = 2099 \ mm^2$$

Calculation with AxisVM:

AXT = $2093 \ mm^2/m$

Different = -0,3 %

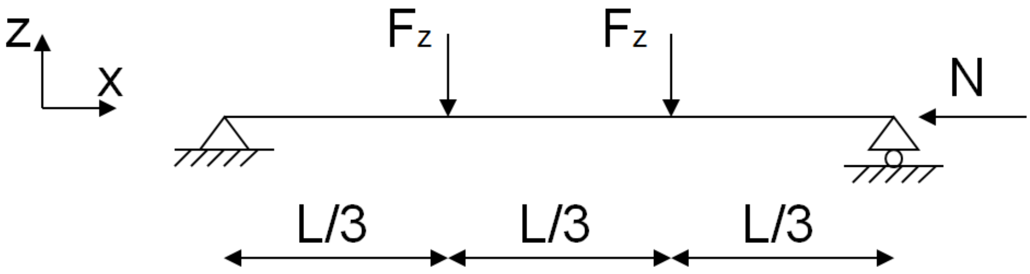
Software Release Number: X5r1
Date: 08. 11. 2018.
Tested by: InterCAD
File name: 3_10 Plastic biaxial bending interaction.axs

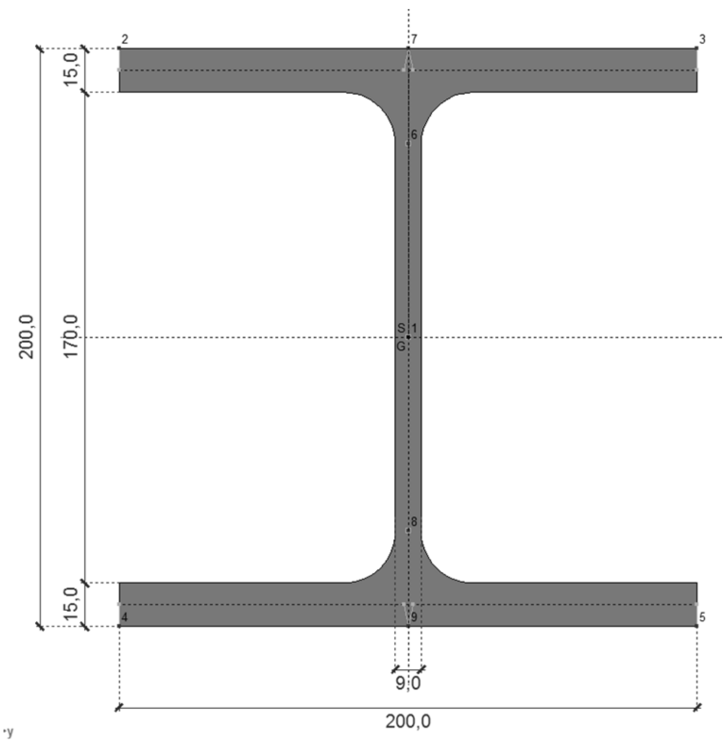
Thema	Interaction check of simply supported beam under biaxial bending (EN 1993-1-1).
Analysis Type	Steel Design
Geometry	  IPE270 cross section h = 270 mm b = 135 mm t_f = 10 mm t_w = 7 mm l = 6000 mm A = 45,95 cm^2 $W_{y,pl}$ = 484,1 cm^3 $W_{z,pl}$ = 97 cm^3
Loads	q_y = 1,5 kN/m q_z = 20,4 kN/m
Boundary Conditions	eX = eY = eZ = 0 at A eY = eZ = 0 at B
Material Properties	S 235 E = 21000 kN/cm^2 ν = 0,3
Element	Beam element

types	
Target	Interaction check taking into account plastic resistances
Results	Analytical solution in the following book: Dunai, L., Horváth, L., Kovács, N., Verőci, B., Vigh, L. G.: “Acélszerkezetek méretezése az Eurocode 3 alapján, Gyakorlati útmutató” (Design of steel structures according to Eurocode 3,) Magyar Mérnöki Kamara Tartószerkezeti tagozata, Budapest, 2009. Exercise 3.10., page 28.

	Analitical solution	AxisVM	e[%]
$M_{y,Ed}$ [kNm]	91,8	91,8	-
$M_{z,Ed}$ [kNm]	6,75	6,75	-
$M_{pl,y,Rd}$ [kNm]	113,74	114,57	+0,07
$M_{pl,z,Rd}$ [kNm]	22,78	22,78	+0,00
α	2	2	-
β	1	1	-
capacity ratio [-]	0,948	0,938	-1.05

Software Release Number: X5r1
Date: 07. 11. 2018.
Tested by: InterCAD
File name: 3_12 _MNV_Interaction.axs

<table>
<tr><td>Thema</td><td>Interaction check of simply supported beam under normal force, bending and shear force. (EN 1993-1-1, EN 1993-1-5)</td></tr>
<tr><td>Analysis Type</td><td>Steel Design</td></tr>
<tr><td>Geometry</td><td>




h = 200 mm
b = 200 mm
t_f = 15 mm
t_w = 9 mm

l = 1400 mm

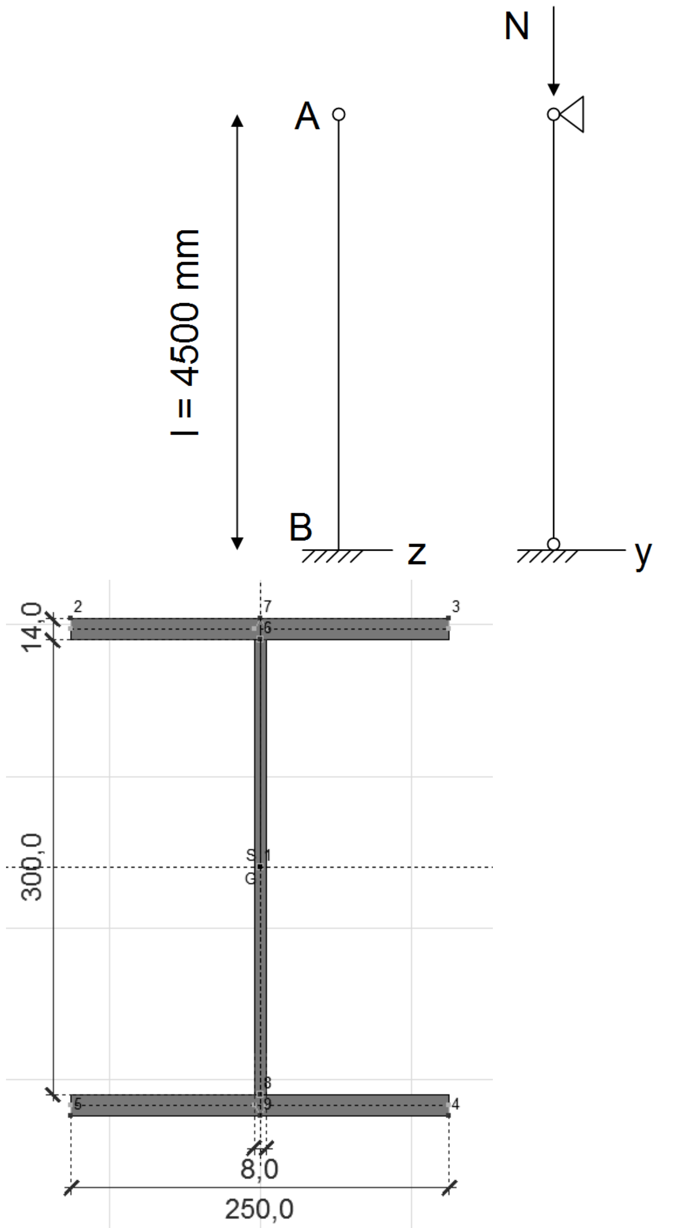
A = 78,1 cm^2
A_v = 24,83 cm^2
I_y = 5696 cm^3
$W_{y,pl}$ = 643 cm^3

IPE270 cross section</td></tr>
<tr><td>Loads</td><td>F_z = 300 kN at thirds of beam
N = 500 kN at B</td></tr>
<tr><td>Boundary Conditions</td><td>eX = eY = eZ = fiX = 0 at A
eY = eZ = fiX =0 at B</td></tr>
<tr><td>Material Properties</td><td>S 235
E = 21000 kN/cm^2
ν = 0,3</td></tr>
<tr><td>Element types</td><td>Beam element</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Target</td><td>Interaction check of axial force, shear force and bending moment.</td></tr>
</table>

Results	Analytical solution in the following book: Dunai, L., Horváth, L., Kovács, N., Verőci, B., Vigh, L. G.: “Acélszerkezetek méretezése az Eurocode 3 alapján, Gyakorlati útmutató” (Design of steel structures according to Eurocode 3,) Magyar Mérnöki Kamara Tartószerkezeti tagozata, Budapest, 2009. Exercise 3.12., page 31-33.

	Analytical solution	AxisVM results	e[%]
N_{Ed} [kN]	500	500	-
$V_{z,Ed}$ [kN]	300	300	-
$M_{y,Ed}$ [kNm]	140	140	-
Pure compression			
$N_{pl,Rd}$ [kN]	2148	2147,6	-0,02-
capacity ratio [-]	0,233	0,233	-
Pure shear			
$V_{pl,z,Rd}$ [kN]	394,2	394,5	+0,08
capacity ratio [-]	0,761	0,761	-
Pure bending			
$M_{pl,y,Rd}$ [kNm]	176,8	178,4	+0,9
capacity ratio [-]	0,792	0,792	-
Interaction check			
ρ	0,273	0,271	-0,73
$M_{V,Rd}$ [kNm]	163,96	165,57	+0,98
n	0,233	0,233	-
a	0,232	0,232	-
$M_{NV,Rd}$ [kNm]	142,2	143,67	+1,03
capacity ratio [-]	0,985	0,974	-1,1

Software Release Number: X5r1
Date: 07. 11. 2018.
Tested by: InterCAD
File name: 3_15 Központosan nyomott rúd - I szelvény.axs

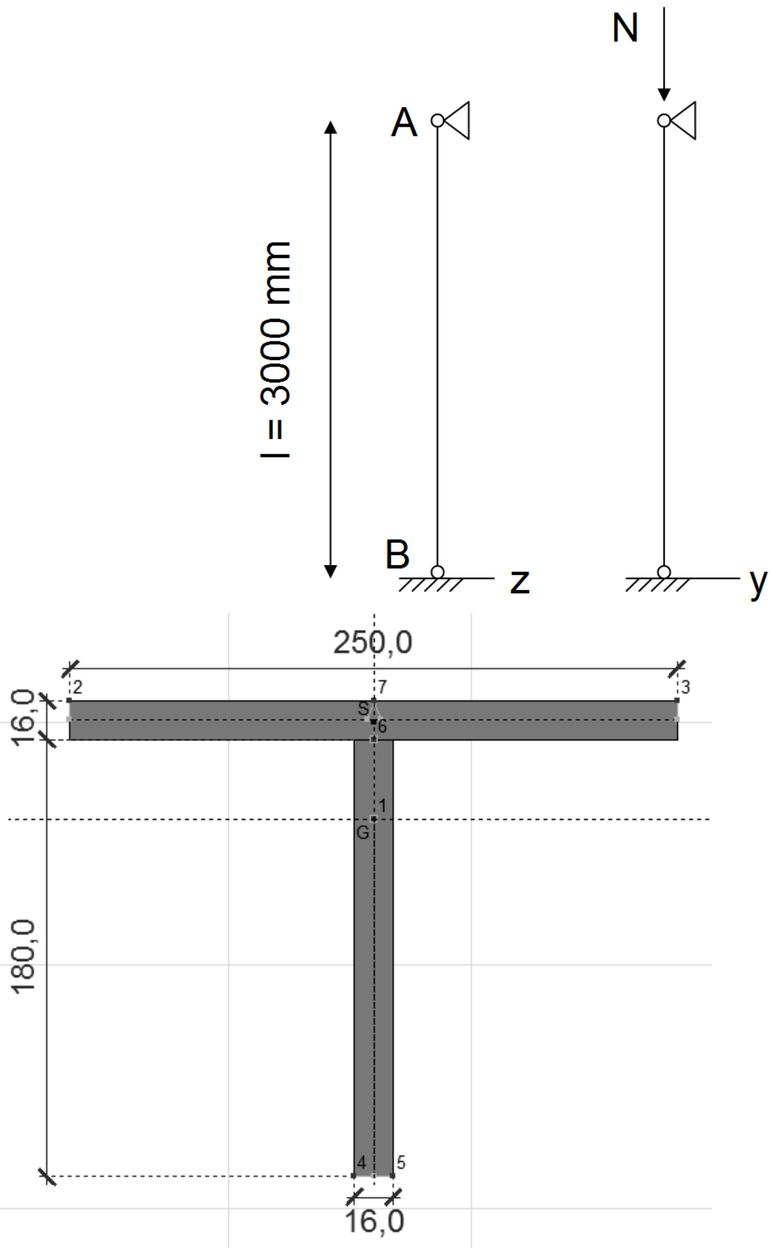
Thema	Buckling resistance of simply supported beam (EN 1993-1-1).
Analysis Type	Steel Design
Geometry	 h = 300 mm b = 250 mm t_f = 14 mm t_w = 8 mm l = 4500 mm A = 94 cm^2 I_y = 19065,8cm^4 I_z = 3647,1 cm^4 i_y = 14,1 cm i_z = 6,2 cm "I" cross section, symmetric about y and z axis
Loads	Normal force at point A N_A= -1,0 kN
Boundary Conditions	eY = 0 at A eX = eY = eZ = fiX = fiZ= 0 at B k_z = k_w = 1
Material Properties	S 235 E = 21000 kN / cm^2 ν = 0,3
Element types	Beam element
Target	Buckling resistance $N_{b,Rd}$ = ?
Results	Analytical solution in the following book:

Dunai, L., Horváth, L., Kovács, N., Verőci, B., Vigh, L. G.: “Acélszerkezetek méretezése az Eurocode 3 alapján, Gyakorlati útmutató” (Design of steel structures according to Eurocode 3,) Magyar Mérnöki Kamara Tartószerkezeti tagozata, Budapest, 2009.

Exercise 3.15., P. 37-39.

	Analytical solution	AxisVM	e[%]
$\bar{\lambda}_y$ [-]	0,673	0,673	-
$\bar{\lambda}_z$ [-]	0,771	0,769	-0,26
X_y [-]	0,8004	0,7989	-0,19
X_z [-]	0,6810	0,6815	+0,07
$N_{b,Rd}$ [kN]	1504,3	1505,3	+0,07

Software Release Number: X5r1
Date: 08. 11. 2018.
Tested by: InterCAD
File name: 3_21 Központosan nyomott rúd - T szelvény.axs

Thema	Buckling resistance of simply supported beam (EN 1993-1-1).
Analysis Type	Steel Design
Geometry	 h = 180 mm b = 250 mm t_f = 16 mm t_w = 16 mm l = 3000 mm A = 68,8 cm^2 I_y = 2394,25 cm^4 I_z = 2089,48 cm^4 I_{cs} = 58,71 cm^4 I_w = 1108,0 cm^6 i_y = 5,90 cm i_z = 5,51 cm Welded “T” section, symmetric to z but not y
Loads	Normal force at point A N_A= -1,0 kN
Boundary Conditions	eZ = eY = 0 at A eX = eY = eZ = fiX = 0 at B $k_z = k_w = 1$
Material Properties	S 235 E = 21000 kN/cm^2 ν = 0,3
Element types	Beam element
Target	Buckling resistance $N_{b,Rd}$ = ?
Results	Analytical solution in the following book:

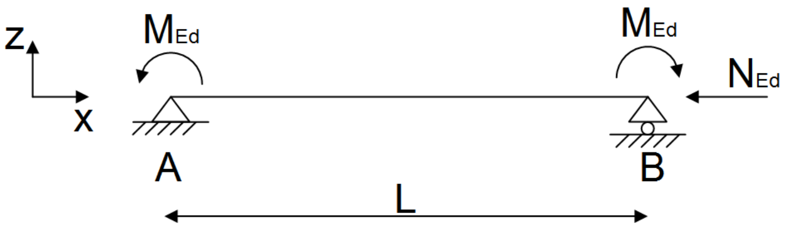
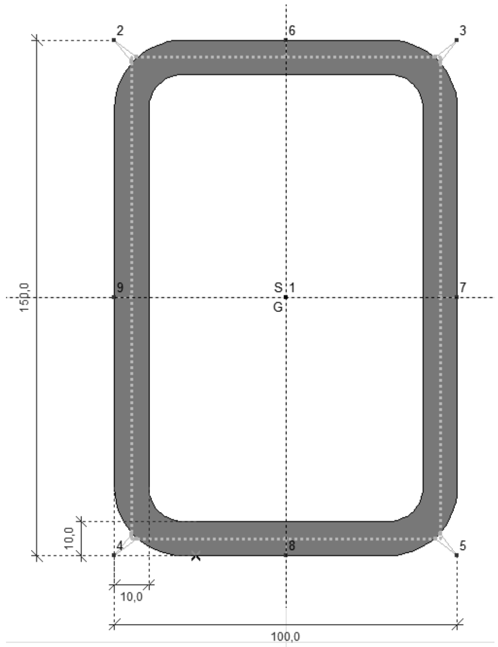
Dunai, L., Horváth, L., Kovács, N., Verőci, B., Vigh, L. G.: “Acélszerkezetek méretezése az Eurocode 3 alapján, Gyakorlati útmutató” (Design of steel structures according to Eurocode 3,) Magyar Mérnöki Kamara Tartószerkezeti tagozata, Budapest, 2009.

Exercise 3.21., P. 47-49.

	Analitical solution	AxisVM	e[%]
z_s [cm]	49,0	49,0	-
z_w [cm]	4,10	4,04	-1,46
i_w [cm] *	9,05	9,03	-0,22
$\overline{\lambda}_y$ [-]	0,542	0,542	-
X_y [-]	0,8204	0,8195	-0,11
$N_{b,Rd,1}$ [kN]	1326,4	1325,0	-0,11
$\overline{\lambda}_{TF}$ [-] *	0,667	0,667	-
X_{TF} [-]	0,7432	0,7446	+0,19
$N_{b,Rd,2}$ [kN]	1201,6	1203,9	+0,19

* hidden partial results, Axis does not show them among the steel design results

Software Release Number: X5r1
Date: 08. 11. 2018.
Tested by: InterCAD
File name: Külpontosan nyomott rúd - RHS szelvény.axs

Topic	Buckling of a hollow cross-section beam (EN 1993-1-1).
Analysis Type	Steel Design
Geometry	  h = 150 mm b = 100 mm t_f = 10 mm t_w = 10 mm L = 4,000 m A = 43,41 cm^2 I_y = 1209,8 cm^4 I_z = 635,7 cm^4 i_y = 52,8 mm i_z = 38,3 mm $W_{el,y}$ = 161,3 cm^3 $W_{el,z}$ = 127,1 cm^3 $W_{pl,y}$ = 205,6 cm^3 $W_{pl,z}$ = 154,6 cm^3 RHS 150x100x10,0 cross section (hot rolled)
Loads	Bending moment at both ends of beam and axial force $N_{Ed,C}$ = 200 kN $M_{Ed,A}$ = $M_{Ed,B}$ = 20 kNm
Boundary Conditions	eX = eY = eZ = 0, warping free at A eY = eZ = 0, warping free at B
Material Properties	S 275 E = 21000 kN / cm^2 ν = 0,3
Element types	Beam element
Steel Design Parameters	Buckling length: L_y = L L_z = L L_w = L
Target	Check for interaction of compression and bending.

Results	Analytical solution:

Section class: 1.

Compression – flexural buckling

$$N_{cr,y} = \frac{\pi^2 E I_y}{K_y L} = \frac{\pi^2 21000 \cdot 1209{,}8}{400^2} = 1567{,}2 \text{ kN}$$

$$N_{cr,z} = \frac{\pi^2 E I_z}{K_z L} = \frac{\pi^2 21000 \cdot 635{,}7}{400^2} = 823{,}5 \text{ kN}$$

$$N_{pl,Rd} = A \cdot f_y = 43{,}41 \cdot 27{,}5 = 1193{,}8 \text{ kN}$$

$$\bar{\lambda}_y = \sqrt{\frac{N_{pl}}{N_{cry}}} = \sqrt{\frac{1193{,}8}{1567{,}16}} = 0{,}8728$$

$$\bar{\lambda}_z = \sqrt{\frac{N_{pl}}{N_{crz}}} = \sqrt{\frac{1193{,}8}{823{,}48}} = 1{,}2040$$

imperfection factor based on buckling curve "a" (hot rolled RHS section):

$$\alpha_y = \alpha_z = 0{,}21$$

$$\phi = \frac{1 + \alpha \cdot (\bar{\lambda} - 0.2) + \bar{\lambda}^2}{2}$$

$$\chi := \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}}$$

$$\chi_y = 0{,}7516$$

$$\chi_z = 0{,}5275$$

$$N_{b,Rd} = \frac{\chi_y A f_y}{\gamma_1} = \frac{0{,}5275 \cdot 43{,}41 \text{ cm}^2 \cdot 27{,}5 \text{ kN/cm}^2}{1{,}0} = 629{,}72 \text{ kN} > N_{Ed,x} = 200 \text{ kN}$$

Bending – lateral torsional buckling

$$M_{pl,Rd,y} = \frac{W_{pl,y} f_y}{\gamma_1} = \frac{205{,}6 \text{ cm}^3 \cdot 27{,}5 \text{ kN/cm}^2}{1{,}0} = 56{,}54 \text{ kNm} > M_{Ed} = 10 \text{ kNm}$$

$$C_1 = 1{,}000 \qquad k_z = k_w = 1$$

$$M_{cr} = C_1 \frac{\pi^2 E I_z}{(kL)^2} \sqrt{\left(\frac{k_z}{k_w}\right)^2 \frac{I_w}{I_z} + \frac{(kL)^2 G I_t}{\pi^2 E I_z}} =$$

$$M_{cr} = 1{,}0 \cdot \frac{\pi^2 \, 21000 \, \frac{\text{kN}}{\text{cm}^2} \cdot 635{,}7 \text{cm}^4}{(400 \text{ cm})^2} \sqrt{\frac{766 \text{ cm}^6}{635{,}7 \text{ cm}^4} + \frac{(400 \text{ cm})^2 \cdot 8077 \, \frac{\text{kN}}{\text{cm}^2} \cdot 1436{,}2 \text{ cm}^4}{\pi^2 \cdot 21000 \, \frac{\text{kN}}{\text{cm}^2} \cdot 635{,}7 \text{ cm}^4}}$$

$$M_{cr} = 977{,}41 \text{ kNm}$$

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_y f_y}{M_{cr}}} = \sqrt{\frac{205{,}6 \text{ cm}^3 \cdot 27{,}5 \text{ kN/cm}^2}{977{,}41 \text{ kNm}}} = 0{,}2405$$

$\bar{\lambda}_{LT} > 0,2$ → torsional buckling may occur

$$\alpha_{LT} = 0,76$$

$$\phi = \frac{1 + \alpha_{LT}(\bar{\lambda}_{LT} - 0.2) + \bar{\lambda}_{LT}^2}{2} = 0,5443$$

$$\chi_{LT} := \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}_{LT}^2}} = 0,9684$$

$$M_{b,Rd} = \chi_{LT} \cdot M_{pl,Rd,y} = 0,9684 \cdot 56,54kNm = 54,76kNm$$

<u>Interaction of bending and buckling</u>

$$N_{Rk} = A \cdot f_y = 43,41\ cm^2 \cdot 27,5\ kN/cm^2 = 1193,8\ kN$$

$$M_{y,Rk} = M_{pl,Rd,y} = 56,54kNm$$

Equivalent uniform moment factors according to EN 1993-1-1 Annex B, Table B.3.:

$$\phi = 1,0$$

$$C_{my} = 0,6 + 0,4\phi = 1,0 > 0,4$$

For members susceptible to torsional deformations the interaction factors may be calculated according to EN 1993-1-1 Annex B, Table B.2.:

$$k_{yy} = C_{my}\left\{1 + (\bar{\lambda}_{LT} - 0,2)\frac{N_{Ed}}{\chi_y N_{Rk}/\gamma_{M1}}\right\} < C_{my}\left\{1 + 0,8\frac{N_{Ed}}{\chi_y N_{Rk}/\gamma_{M1}}\right\}$$

$$k_{yy} = 1,0\left\{1 + (0,87 - 0,2)\cdot\frac{200}{0,7531 \cdot 1193,78/1,0}\right\} < 1,0\left\{1 + 0,8\cdot\frac{200}{0,7531 \cdot 1193,78/1,0}\right\}$$

$$k_{yy} = \min(1,149\ ; 1,178) = 1,149$$

$$k_{zy} = \left\{1 - \frac{0,1 \cdot \bar{\lambda}_z}{C_{mLT} - 0,25}\cdot\frac{N_{Ed,x}}{\chi_z N_{Rk}/\gamma_{M1}}\right\} \geq \left\{1 - \frac{0,1}{C_{mLT} - 0,25}\cdot\frac{N_{Ed,x}}{\chi_z N_{Rk}/\gamma_{M1}}\right\}$$

$$k_{zy} = \left\{1 - \frac{0,1 \cdot 1,2040}{1,0 - 0,25}\cdot\frac{200}{0,5275 \cdot 1193,78/1,0}\right\} \geq \left\{1 - \frac{0,1}{1,0 - 0,25}\cdot\frac{200}{0,5275 \cdot 1193,78/1,0}\right\}$$

$$k_{zy} = \max(0,9490\ ; 0,9577) = 0,9577$$

$$\frac{N_{Ed}}{\chi_y \cdot N_{Rk}/\gamma_{M1}} + k_{yy}\frac{M_{y,Ed}}{\chi_y \cdot M_{y,Rk}/\gamma_{M1}} =$$

$$= \frac{200}{0,7516 \cdot 1193,78} + 1,149 \cdot \frac{20}{0,9684 \cdot 56,54} = 0,6426$$

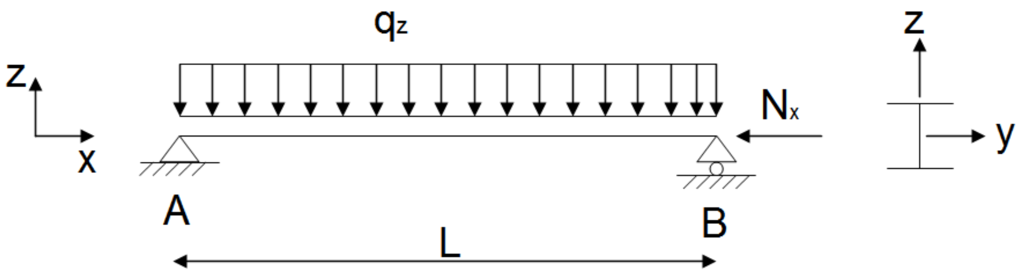
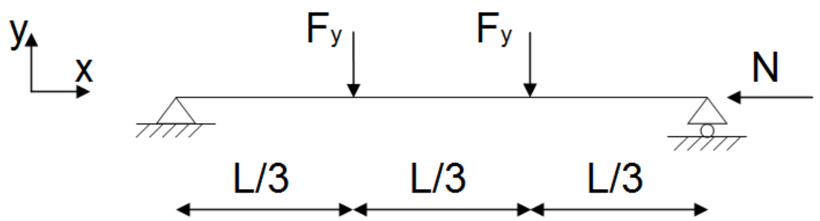
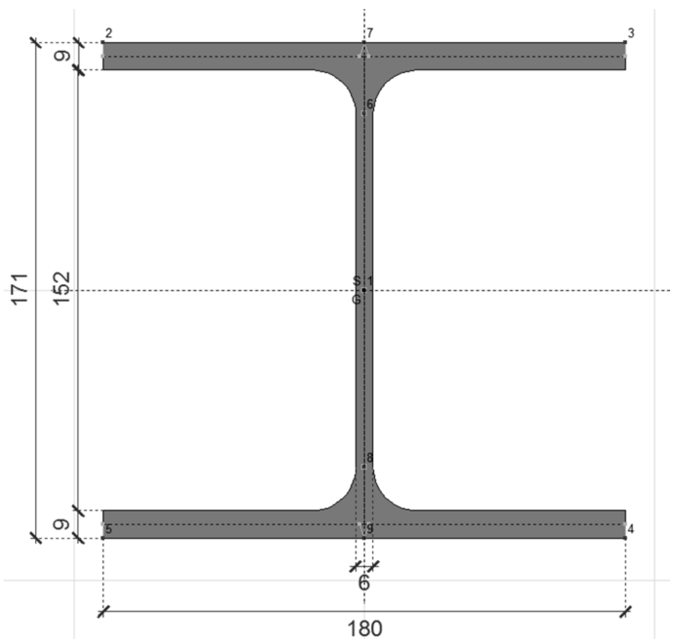
$$\frac{N_{Ed}}{\chi_z \cdot N_{Rk}/\gamma_{M1}} + k_{zy}\frac{M_{y,Ed}}{M_{y,Rk}/\gamma_{M1}} =$$

$$= \frac{200}{0,5275 \cdot 1193,78} + 0,9577 \cdot \frac{20}{0,9684 \cdot 56,54} = 0,6674$$

	Analytical solution	AxisVM	e [%]

$N_{Rk} = N_{pl,Rd}$ [kN]	1193,8	1193,9	-
$\bar{\lambda}_y$ [-]	0,873	0,870	-0,34
$\bar{\lambda}_z$ [-]	1,204	1,201	-0,25
X_y [-]	0,7516	0,7513	-0,04
X_z [-]	0,5275	0,5271	-0,08
$N_{b,Rd}$ [kN]	629,7	629,23	-0,10
$M_{c,Rd} = M_{pl,Rd}$ [kNm]	56,54	56,54	-
C_1	1,000	1,000	-
M_{cr} [kNm]	977,41	989,66	+1,25
$\bar{\lambda}_{LT}$ [-]	0,2405	0,2405	-
X_{LT} [-]	0,9684	1,000	-
$M_{b,Rd}$ [kNm]	54,76	56,54	+3,25
C_{my} [-]	1,0	1,0	-
k_{yy} [-]	1,149	1,150	+0,087
k_{zy} [-]	0,9577	0,69	-27,95
Interaction capacity ratio 1 [-]	0,643	0,643	-
Interaction capacity ratio 2 [-]	0,667	0,667	-

Software Release Number: X5r1
Date: 09. 11. 2018.
Tested by: InterCAD
File name: 3_26 Külpontosan nyomott rúd - I szelvény.axs

Thema	Lateral torsional buckling of a beam (EN 1993-1-1).
Analysis Type	Steel Design
Geometry	   HEA180 h = 171 mm b = 180 mm t_f = 6 mm t_w = 9,5 mm L = 4,000 m A = 45,26 cm^2 I_y = 2510,7 cm^4 I_z = 924,6 cm^4 i_y = 74 mm i_z = 45 mm $W_{el,y}$ = 293,7 cm^3 $W_{el,z}$ = 102,7 cm^3 $W_{pl,y}$ = 324,9 cm^3 $W_{pl,z}$ = 156,5 cm^3 I_w = 58932 cm^6 I_t = 15 cm^4
Loads	Axial force at B: N_x = -280 kN Point load in y direction at the thirds of the beam: F_y = 5 kN Distributed load in z direction: q_z = 4,5 kNm
Boundary Conditions	eX = eY = eZ = 0, warping free at A eY = eZ = 0, warping free at B
Material Properties	S 235 E = 21000 kN / cm^2 ν = 0,3
Element types	Beam element

Steel Design Parameters

The elastic critical load factor is:
α_{cr} = 4,28
As α_{cr} = 4,28 < 15 → II. order analysis is required.
For this, the beam element needs to be meshed. Divison of the beam element into 4.

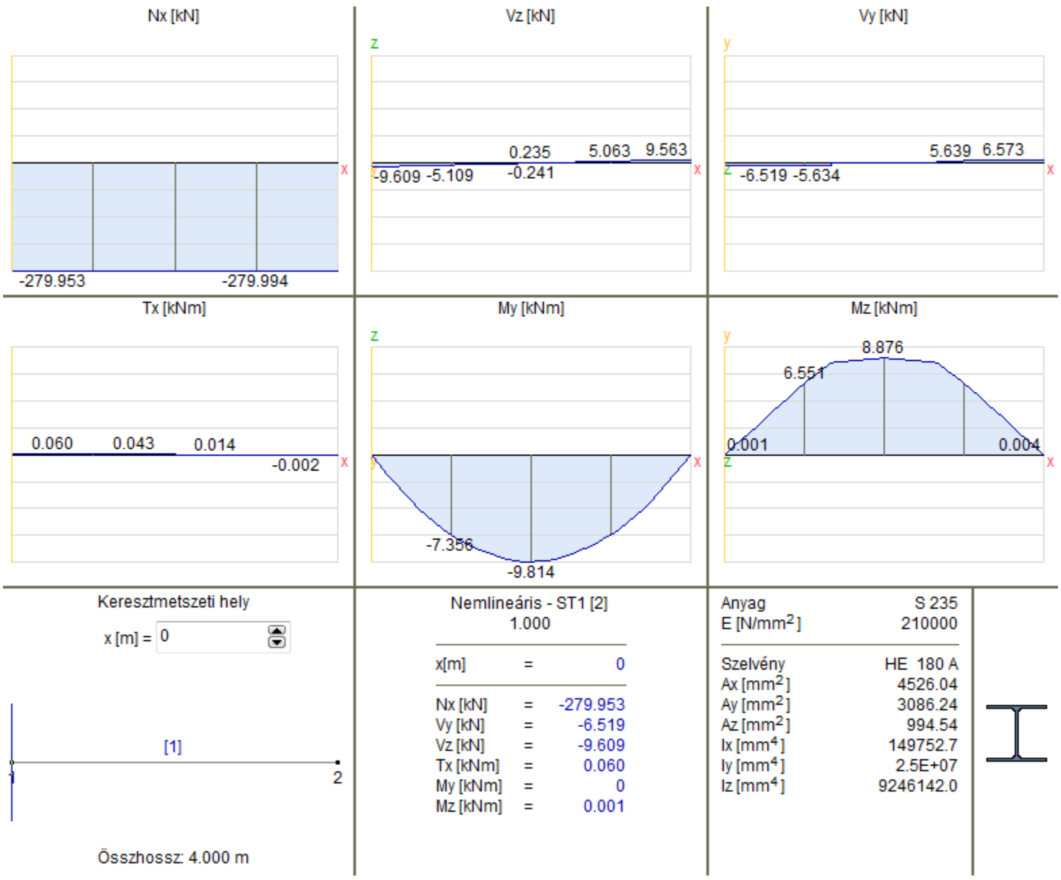
Buckling length:
$L_y = L$
$L_z = L$
LT buckling length:
$L_w = L$

Target

Buckling check for interaction of axial force and bi-axial bending.

Results

Internal forces from the second order analysis



$N_{Ed,x}$ = 280 kN $M_{Ed,y}$ = 9,81 kNm $M_{Ed,z}$ = 8,88 kNm $V_{Ed,y}$ = 6,52 kN $V_{Ed,z}$ = 9,61 kN

Analytical solution:

Section class: 1.

Normal force

$$N_{cr,y} = \frac{\pi^2 E I_y}{K_y L} = \frac{\pi^2 \, 21000 \cdot 2510{,}7}{400} = 3252{,}3 \text{ kN}$$

$$N_{cr,z} = \frac{\pi^2 E I_z}{K_z L} = \frac{\pi^2 \, 21000 \cdot 924{,}6}{400} = 1197{,}7 \text{ kN}$$

$$N_{pl,Rd} = A \cdot f_y = 45{,}26 \cdot 23{,}5 = 1063{,}6 \text{ kN}$$

$$\bar{\lambda}_y = \sqrt{\frac{N_{pl}}{N_{cry}}} = \sqrt{\frac{1063{,}6}{3252{,}3}} = 0{,}5719$$

$$\bar{\lambda}_z = \sqrt{\frac{N_{pl}}{N_{crz}}} = \sqrt{\frac{1063{,}6}{1197{,}7}} = 0{,}9424$$

based on buckling curve “b” in y direction and “c” in z direction:

$$\chi_y = 0{,}8508$$

$$\chi_z = 0{,}5741$$

$$N_{b,Rd,1} = \frac{\chi_y A f_y}{\gamma_1} = \frac{0{,}8508 \cdot 45{,}26\text{cm}^2 \cdot 23{,}5\text{kN/cm}^2}{1{,}0} = 904{,}92 \text{ kN} > N_{Ed,x} = 280 \text{ kN}$$

$$N_{b,Rd,2} = \frac{\chi_z A f_y}{\gamma_1} = \frac{0{,}5741 \cdot 45{,}26\text{cm}^2 \cdot 23{,}5\text{kN/cm}^2}{1{,}0} = 610{,}62 \text{ kN} > N_{Ed,x} = 280 \text{ kN}$$

Bending

$$M_{pl,Rd,y} = \frac{W_{pl,y} f_y}{\gamma_1} = \frac{324{,}9 \text{ cm}^3 \cdot 23{,}5 \text{ kN/cm}^2}{1{,}0} = 76{,}35 \text{ kNm} > M_{Ed,y} = 9{,}81 \text{ kNm}$$

$$M_{pl,Rd,z} = \frac{W_{pl,z} f_y}{\gamma_1} = \frac{156{,}5 \text{ cm}^3 \cdot 23{,}5 \text{ kN/cm}^2}{1{,}0} = 36{,}78 \text{ kNm} > M_{Ed,z} = 8{,}88 \text{ kNm}$$

Calculation of the critical moment:

$C_1 = 1{,}132$ (due to the M_y moment diagram)

$$M_{cr} = C_1 \frac{\pi^2 E I_z}{(kL)^2} \sqrt{\left(\frac{k_z}{k_w}\right)^2 \frac{I_w}{I_z} + \frac{(kL)^2 G I_t}{\pi^2 E I_z}} =$$

$$M_{cr} = 1{,}132 \frac{\pi^2 \, 21000 \text{ kN/cm}^2 \cdot 924{,}6 \text{ cm}^4}{(400 \text{ cm})^2} \sqrt{\frac{58932 \text{ cm}^6}{924{,}6 \text{ cm}^4} + \frac{(400 \text{ cm})^2 \cdot 8077 \text{ kN/cm}^2 \cdot 15 \text{ cm}^4}{\pi^2 \cdot 21000 \text{ kN/cm}^2 \cdot 924{,}6 \text{ cm}^4}}$$

$$M_{cr} = 174{,}1 \text{kNm}$$

For rolled section, the following procedure may be used to determine the reduction factor (EN 1993-1-1,Paragraph 6.3.2.3.):

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_y\ f_y}{M_{cr}}} = \sqrt{\frac{324{,}9\ cm^3 \cdot 23{,}5\ kN/cm^2}{174{,}10\ kNm}} = 0{,}6622$$

$$\phi = \frac{1 + \alpha_{LT}(\bar{\lambda}_{LT} - 0.4) + 0.75 \cdot \bar{\lambda}_{LT}^2}{2} = 0{,}7090$$

$$\chi_{LT} := \frac{1}{\phi + \sqrt{\phi^2 - 0.75 \cdot \bar{\lambda}_{LT}^2}} = 0{,}8881$$

$$M_{b,Rd} = \chi_{LT} \cdot M_{pl,Rd,y} = 0{,}8881 \cdot 76{,}35 kNm = 67{,}81 kNm$$

Interaction of axial force and bi-axial bending

$$N_{Rk} = N_{pl,Rd} = 1063{,}6\ kN$$

$$M_{y,Rk} = M_{pl,Rd,y} = 76{,}35\ kNm$$

$$M_{z,Rk} = M_{pl,Rd,z} = 36{,}78\ kNm$$

Equivalent uniform moment factors according to EN 1993-1-1 Annex B, Table B.3.:

$\psi = 0, \alpha = 0$ in both directions

$C_{my} = C_{mLT} = 0{,}95 + 0{,}05\alpha = 0{,}95$ (distributed load)

$C_{mz} = 0{,}90 + 0{,}10\alpha = 0{,}90$ (concentrated load)

$$k_{yy} = C_{my}\left\{1 + (\bar{\lambda}_y - 0{,}2)\frac{N_{Ed,x}}{\chi_y N_{Rk}/\gamma_{M1}}\right\} \le C_{my}\left\{1 + 0{,}8\frac{N_{Ed,x}}{\chi_y N_{Rk}/\gamma_{M1}}\right\}$$

$$k_{yy} = 0{,}95 \cdot \left\{1 + (0{,}5719 - 0{,}2) \cdot \frac{280}{0{,}8508 \cdot 1063{,}6\ /1{,}0}\right\} \le 0{,}95 \cdot \left\{1 + 0{,}8 \cdot \frac{280}{0{,}8508 \cdot 1063{,}6\ /1{,}0}\right\}$$

$$k_{yy} = \min\ (1{,}0593\ ; 1{,}1851) = 1{,}0593$$

$$k_{zy} = \left\{1 - \frac{0{,}1 \cdot \bar{\lambda}_z}{C_{mLT} - 0{,}25} \cdot \frac{N_{Ed,x}}{\chi_z N_{Rk}/\gamma_{M1}}\right\} \ge \left\{1 - \frac{0{,}1}{C_{mLT} - 0{,}25} \cdot \frac{N_{Ed,x}}{\chi_z N_{Rk}/\gamma_{M1}}\right\}$$

$$k_{zy} = \left\{1 - \frac{0{,}1 \cdot 0{,}9424}{0{,}95 - 0{,}25} \cdot \frac{280}{0{,}5741 \cdot 1063{,}6\ /1{,}0}\right\} \ge \left\{1 - \frac{0{,}1}{0{,}95 - 0{,}25} \cdot \frac{280}{0{,}5741 \cdot 1063{,}6\ /1{,}0}\right\}$$

$$k_{zy} = \max\ (0{,}9383\ ; 0{,}9345) = 0{,}9383$$

$$k_{zz} = C_{mz}\left\{1+(2\cdot\bar{\lambda}_z - 0,6)\frac{N_{Ed,x}}{\chi_z N_{Rk}/\gamma_{M1}}\right\} \le C_{mz}\left\{1+1,4\frac{N_{Ed,x}}{\chi_z N_{Rk}/\gamma_{M1}}\right\}$$

$$k_{zz} = 0,90\left\{1+(2\cdot 0,9424 - 0,6)\frac{280}{0,5741\cdot 1063,6\ /1,0}\right\} \le 0,90\left\{1+1,4\frac{280}{0,5741\cdot 1063,6\ /1,0}\right\}$$

$$k_{zz} = \min\ (1,4303\ ;1,478) = 1,4303$$

$$k_{yz} = 0,6\ k_{zz} = 0,8582$$

$$\frac{N_{Ed,x}}{\chi_y \cdot N_{Rk}/\gamma_{M1}} + k_{yy}\frac{M_{y,Ed}}{\chi_{LT}\cdot M_{y,Rk}/\gamma_{M1}} + k_{yz}\frac{M_{z,Ed}}{M_{z,Rk}/\gamma_{M1}} =$$

$$= \frac{280}{0,8508\cdot 1063,6} + 1,0593\cdot\frac{9,81}{0,8881\cdot 76,35} + 0,8582\cdot\frac{8,88}{36,78} = 0,6699$$

$$\frac{N_{Ed,x}}{\chi_z \cdot N_{Rk}/\gamma_{M1}} + k_{zy}\frac{M_{y,Ed}}{\chi_{LT}\cdot M_{y,Rk}/\gamma_{M1}} k_{zz}\frac{M_{z,Ed}}{M_{z,Rk}/\gamma_{M1}} =$$

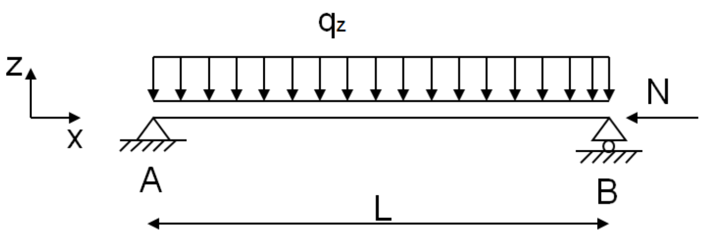
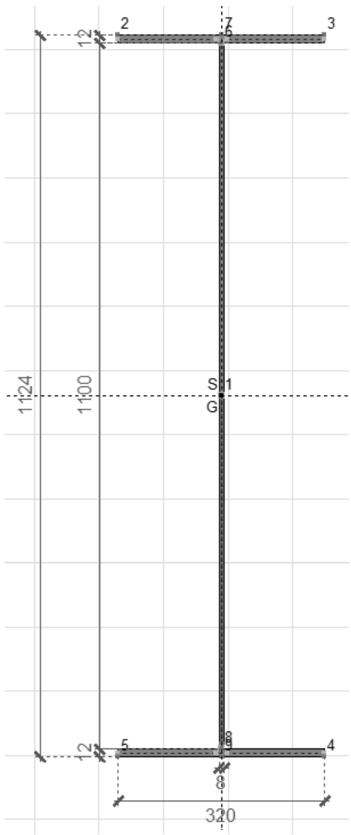
$$= \frac{280}{0,5741\cdot 1063,6} + 0,9383\cdot\frac{9,81}{0,8881\cdot 76,35} + 1,4303\cdot\frac{8,88}{36,78} = 0,9396$$

	Analytical solution	AxisVM	e [%]
$N_{pl,Rd}$ [kN]	1063,6	1063,6	-
$N_{cr,y}$ [kN]	3252,3	3252,4	-
$N_{cr,z}$ [kN]	1197,7	1197,7	-
$\lambda_{y, rel}$ [-]	0,5719	0,5719	-
$\lambda_{z, rel}$ [-]	0,9424	0,9424	-
X_y [-]	0,8508	0,8509	-
X_z [-]	0,5741	0,5741	-
$M_{pl,Rd,y}$ [kNm]	76,35	77,17	+1
$M_{pl,Rd,z}$ [kNm]	36,78	36,78	-
C_1 [-]	1,132	1,13	
M_{cr} [kNm]	174,1	174,08	-0,01
$\lambda_{LT, rel}$ [-]	0,6622	0,6672	+0,7
X_{LT} [-]	0,8881	0,8857	+0,3
$M_{b,Rd}$ [kNm]	67,81	68,41	+0,9
$C_{my} = C_{mLt}$ [-]	0,95	0,95	-
C_{mz} [-]	0,90	0,95	+5,5**
k_{yy}	1,0593	1,0593	-
k_{zz}	1,4303	1,5096	+5,5***
k_{yz}	0,8582	0,9058	+5,5***
k_{zy}	0,9383	0,9383	-
Interaction capacity ratio 1	0,6687	0,6801	+1,7***
Interaction capacity ratio 2	0,9374	0,9564	+2,0***

** See EC3 Annex B, Table B.3: the difference is due to the fact, that AxisVM calculates the equivalent uniform moment factor (C_{my}, C_{mz}, C_{mLT}) for both uniform load and concentrated load, and then takes the higher value. The effect on the final result (efficiency) is +1~2%.

*** the difference is due to the different C_{mz} value

Software Release Number: X5r1
Date: 09. 11. 2018.
Tested by: InterCAD
File name: Double-symmetric I - Class 4.axs

Thema	Interaction check of beam in section class 4 (EN 1993-1-1, EN 1993-1-5)
Analysis Type	Steel Design
Geometry	  Double-symmetric welded I shape h = 1124 mm t_w = 8 mm b = 320 mm t_f = 12 mm L = 8,000 m A = 164,8 cm^2 I_y = 326159,4 cm^4 $W_{el,y}$ = 5803,6 cm^3
Loads	Axial force at B: $N_{Ed,C}$ = 700 kN Distributed load in z direction: q_z = 162,5 kNm The internal forces in the mid-section: $M_{Ed,y}$ = 1300 kNm, $N_{Ed,x}$ = - 700 kN
Boundary Conditions	eX = eY = eZ = fiX = 0 at A eY = eZ = fiX = 0 at B
Material Properties	S 355 E = 21000 kN / cm^2 ε=0,81 ν = 0,3
Element types	Beam element
Target	Check the strength capacity ratios for axial force, bending and interaction.

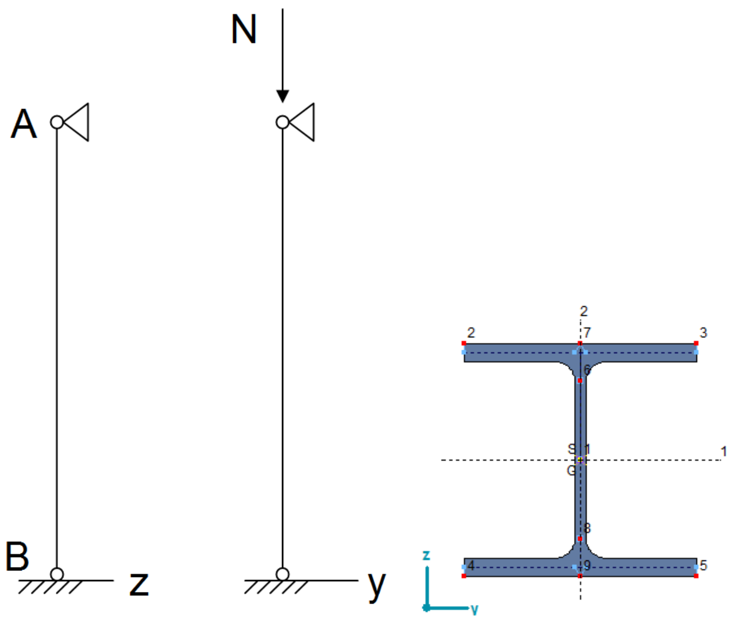
Results	Analytical solution in the following book:

Dunai, L., Horváth, L., Kovács, N., Verőci, B., Vigh, L. G.: "Acélszerkezetek méretezése az Eurocode 3 alapján, Gyakorlati útmutató" (Design of steel structures according to Eurocode 3,) Magyar Mérnöki Kamara Tartószerkezeti tagozata, Budapest, 2009.
Exercise 3.4., P. 14-16.
Exercise 3.6., P. 19-21.
Exercise 3.13., P. 34.

	Analytical solution	AxisVM	e [%]
Uniform compression			
$k_{\sigma,flange}$ [−]	0,43	0,43	-
$\bar{\lambda}_{p,flange}$[−]	0,831	0,858	+3,1
ρ_{flange}[−]	0,931	0,910	-2,3
$b_{eff,f}$[cm]	140,0	142,0	+1,4
$k_{\sigma,web}$[−]	4	4	-
$\bar{\lambda}_{p,web}$[−]	2,957	2,975	+0,6
ρ_{web}[−]	0,313	0,311	-0,6
$b_{eff,web}$[cm]	340,8	342,4	+0,5
A_{eff} [cm^2]	**99,98**	**97,46**	**-2,6**
N_{eff}[kN/cm^2] [kN]	**3549**	**3460**	**+2,6**
capacity ratio: N	**0,2**	**0,2**	**-**
Uniform bending			
$k_{\sigma,flange}$[−]	0,43	0,43	-
$\bar{\lambda}_{p,flange}$[−]	0,831	0,858	+3,1
ρ_{flange}[−]	0,931	0,910	-2,3
$b_{eff,f}$[cm]	139,95	142,0	+1,4
Ψ [−]	-0,969	-0,959	+1,0
$k_{\sigma,web}$ [−]	23,09	22,84	-1,1
$\bar{\lambda}_{p,web}$ [−]	1,231	1,245	+1,1
ρ_{web} [−]	0,739	0,731	-1,1
$b_{eff,web}$ [cm]	408,6	410,4	+0,4
$W_{eff,y,min}$[cm^3]	**5131**	**4976**	**-3,1**
$M_{y,eff,Rd}$ [kNm]	**1821,5**	**1766,5**	**-3,1**
capacity ratio: M	**0,71**	**0,74**	**+4,1**
capacity ratio: N − M interaction	**0,91**	**0,94**	**+3,3**

Small differences occur because AxisVM does not take into account welding when calculating the effective section sizes.

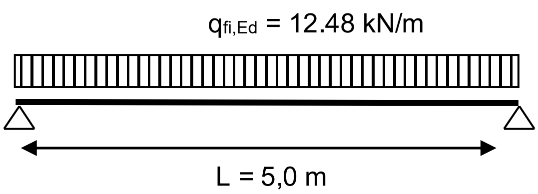
Software Release Number: X5r1
Date: 08. 11. 2018.
Tested by: InterCAD
Reference: Jean-Marc Franssen, Paulo Villa Real: Fire Design of Steel Structures (Example 5.3)
File name: steel_fire.axs

Thema	Fire design of steel elements – Unprotected column under axial compression (EN 1993-1-2)
Analysis Type	Steel Design
Geometry	 Length: L = 3.5m Section: HE180B
Loads	Axial force at A: $N_{fi,Ed}$ = 495 kN R30 required fire resistance
Boundary Conditions	eX = eY = eZ = fiZ = 0 at B eX = eY = 0 at A
Material Properties	S275 E = 21000 kN / cm^2 ν = 0,3
Element types	Beam element

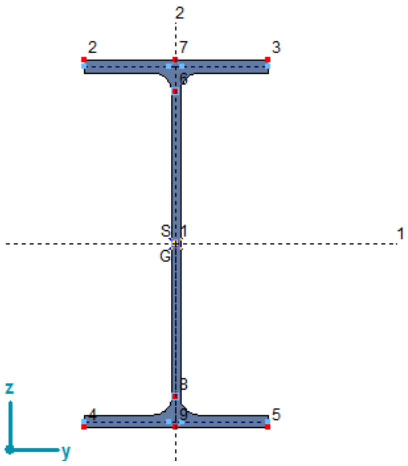
Results

	Analytical solution	AxisVM	e [%]
θ_d [°C]	766	767	+0.1
θ_{cr} [°C]	623	633	+1.6
k_{sh} [-]	0.624	0.61	-2.2
A/V [1/m]	159	162.9	+2.5
$\chi_{z,fi}$ [-]	0.714	0.715	+0.1
$N_{b,fi,Rd}$ [kN]	193	191	-1.0

Software Release Number: X5r1
Date: 08. 11. 2018.
Tested by: InterCAD
Reference: Jean-Marc Franssen, Paulo Villa Real: Fire Design of Steel Structures (Example 5.6)
File name: steel_fire.axs

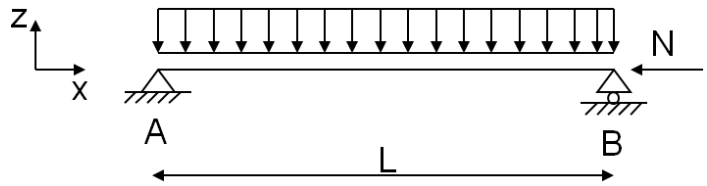
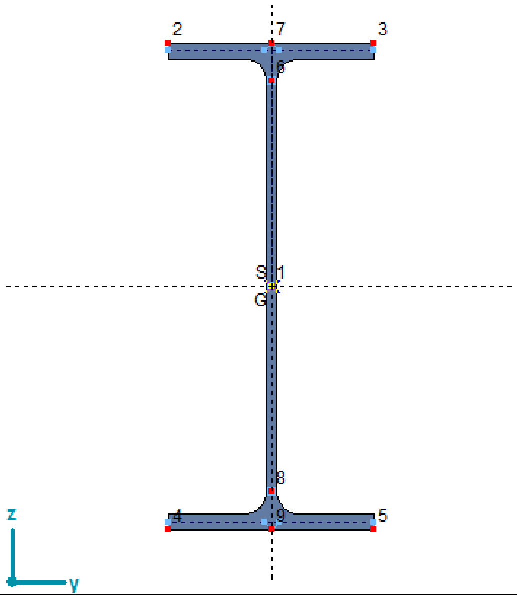
<table>
<tr><td>Thema</td><td>Fire design of steel elements – Unrestrained beam (EN 1993-1-2)</td></tr>
<tr><td>Analysis Type</td><td>Steel Design</td></tr>
<tr><td>Geometry</td><td>

Side view

Section: IPE 300

</td></tr>
<tr><td>Loads</td><td>Distributed load: $q_{fi,Ed}$ = 12.48 kN/m</td></tr>
<tr><td>Boundary Conditions</td><td>eX = eY = eZ = fiX = 0 at A
eY = eZ = fiX = 0 at B</td></tr>
<tr><td>Material Properties</td><td>S 235
E = 21000 kN / cm^2
ν = 0,3</td></tr>
<tr><td>Element types</td><td>Beam element</td></tr>
<tr><td>Target</td><td>Evaluate the critical temperature.</td></tr>
</table>

Results		Analytical solution	AxisVM	e [%]
	θ_{cr} [°C]	519	518	-0.2
	$\overline{\lambda}_{LT,\theta}$ [1/m]	1.222	1.23	+0.66
	$\chi_{LT,fi}$ [-]	0.364	0.362	-0.55
	$M_{b,fi,Rd}$ [kNm]	38.8	38.78	-0.05

Software Release Number: X5r1
Date: 08. 11. 2018.
Tested by: InterCAD
Reference: Jean-Marc Franssen, Paulo Villa Real: Fire Design of Steel Structures (Example 5.7)
File name: steel_fire.axs

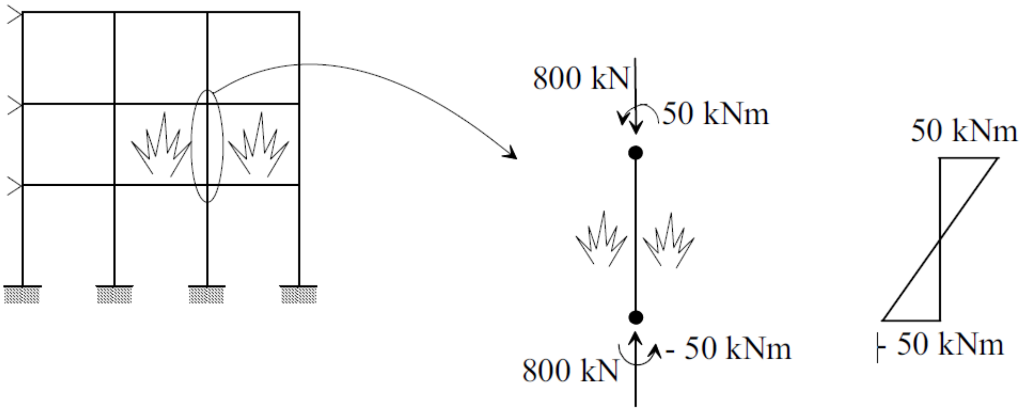
Thema	Fire design of steel elements – Unrestrained beam-column (EN 1993-1-2)
Analysis Type	Steel Design
Geometry	 Length: L= 6.0m Section IPE 450 
Loads	Axial force at B: $N_{fi,Ed}$ = 136.5 kN Distributed load: $q_{fi,Ed}$ = 15.89 kN/m
Boundary Conditions	eX = eY = eZ = fix = 0 at A eY = eZ = fix = 0 at B
Material Properties	S 235 E = 21000 kN / cm^2 ν = 0,3
Element types	Beam element
Target	Evaluate the critical temperature.

Results

	Analytical solution	AxisVM	e [%]
θ_{cr} [°C] (no LTB)	595	596	+0.2
θ_{cr} [°C]	515	517	+0.4
$\chi_{z,fi}$ [-] (512°C)	0.216	0.216	0.0
$\chi_{LT,fi}$ [-] (512°C)	0.361	0.362	+0.3
μ_{LT} [-] (512°C)	0.197	0.2	+1.5
k_{LT} [-] (512°C)	0.928	0.93	+0.2

Software Release Number: X5r1
Date: 08. 11. 2018.
Tested by: InterCAD
Reference: Jean-Marc Franssen, Paulo Villa Real: Fire Design of Steel Structures (Example 5.8)
File name: steel_fire.axs

<table>
<tr><td>Thema</td><td>Fire design of steel elements – Beam-column with restrained lateral displacements (EN 1993-1-2)</td></tr>
<tr><td>Analysis Type</td><td>Steel Design</td></tr>
<tr><td>Geometry</td><td>



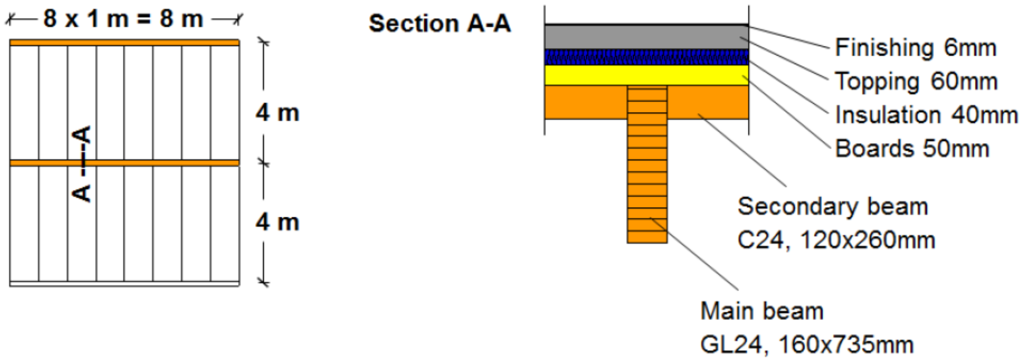
(*Jean-Marc Franssen, Paulo Villa Real: Fire Design of Steel Structures*)

Length: L= 3.0m
Section HE 200B
</td></tr>
<tr><td>Loads</td><td>Axial force: $N_{fi,Ed}$ = 800 kN
Bending moment: $M_{y,fi,Ed}$ = +/-50 kNm</td></tr>
<tr><td>Boundary Conditions</td><td>eX = eY = eZ = fiZ = 0 at B
eX = eY = 0 at A</td></tr>
<tr><td>Material Properties</td><td>S 235
E = 21000 kN / cm^2
ν = 0,3</td></tr>
<tr><td>Element types</td><td>Beam element</td></tr>
</table>

Results

	Analytical solution	AxisVM	e [%]
θ_{cr} [°C] (with buckling)	552	554	+0.4
k_y [-]	0.374	0.35	-6.4
$\chi_{y,fi}$ [-]	0.871	0.8704	-0.07
$V_{pl,fi,Rd}$ [kN]	208.2	208.3	+0.05
$N_{pl,fi,Rd}$ [kN]	1134	1134.1	~0.0
$M_{N,fi,Rd}$ [kNm]	31.2	31.39	+0.6
θ_{cr} [°C] (without buckling; M+N)	516	518	+0.4

Software Release Number: X5r1
Date: 19. 11. 2018.
Tested by: InterCAD
Reference: Eurocodes: Background & Applications Structural Fire Design
File name: timber_fire_1.axs

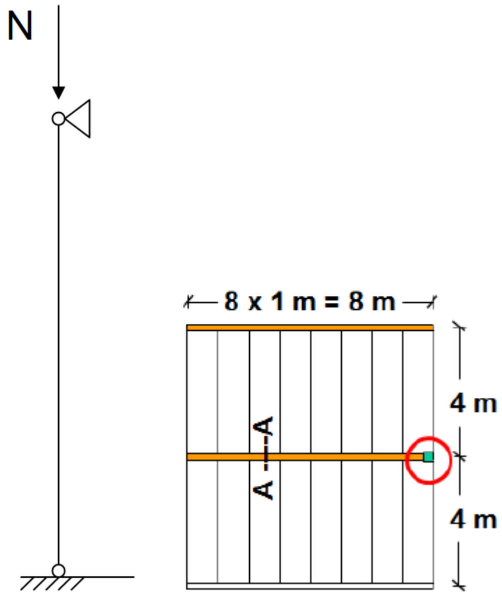
<table>
<tr><td>Thema</td><td>Fire design of timber elements – Unprotected beam (EN 1995-1-2)</td></tr>
<tr><td>Analysis Type</td><td>Timber Design</td></tr>
<tr><td>Geometry</td><td>


Length: L = 8m
Section: 160x735</td></tr>
<tr><td>Loads</td><td>distributed load: $q_{d,fi}$ = 14.76 kN/m
R30 required fire resistance</td></tr>
<tr><td>Boundary Conditions</td><td>eX = eY = eZ = 0 at B
eY = eZ = fiX = 0 at A</td></tr>
<tr><td>Material Properties</td><td>GL24h
E = 1150 kN / cm^2
ν = 0,2</td></tr>
<tr><td>Element types</td><td>Beam element</td></tr>
</table>

Results

	Analytical solution	AxisVM	e [%]
d_{ef} [mm]	28	28	0.0
$\sigma_{m,y,d,fi}$ [N/mm^2]	13.6	13.6	0.0
$f_{m,y,d,fi}$ [N/mm^2]	27.6	27.6	0.0

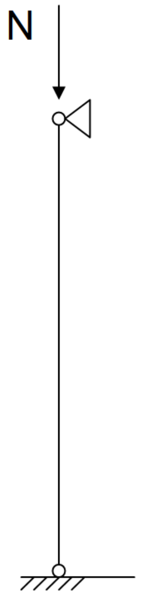
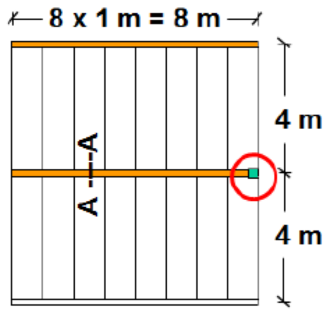
Software Release Number: X5r1
Date: 19. 11. 2018.
Tested by: InterCAD
Reference: Eurocodes: Background & Applications Structural Fire Design
File name: timber_fire_2.axs

Thema	Fire design of timber elements – Unprotected column (EN 1995-1-2)
Analysis Type	Timber Design
Geometry	
Loads	Concentrated load on the top: $N_{d,fi}$ = 59 kN R30 required fire resistance
Boundary Conditions	eX = eY = eZ = fiZ = 0 at the bottom eX = eY = 0 at the top
Material Properties	C24 E = 1100 kN / cm^2 ν = 0,2
Element types	Beam element

Results

	Analytical solution	AxisVM	e [%]
d_{ef} [mm]	31	31	0.0
$k_{c,fi}$ [-]	0.27	0.27	0.0
η [-]	0.86	0.85	-1.0

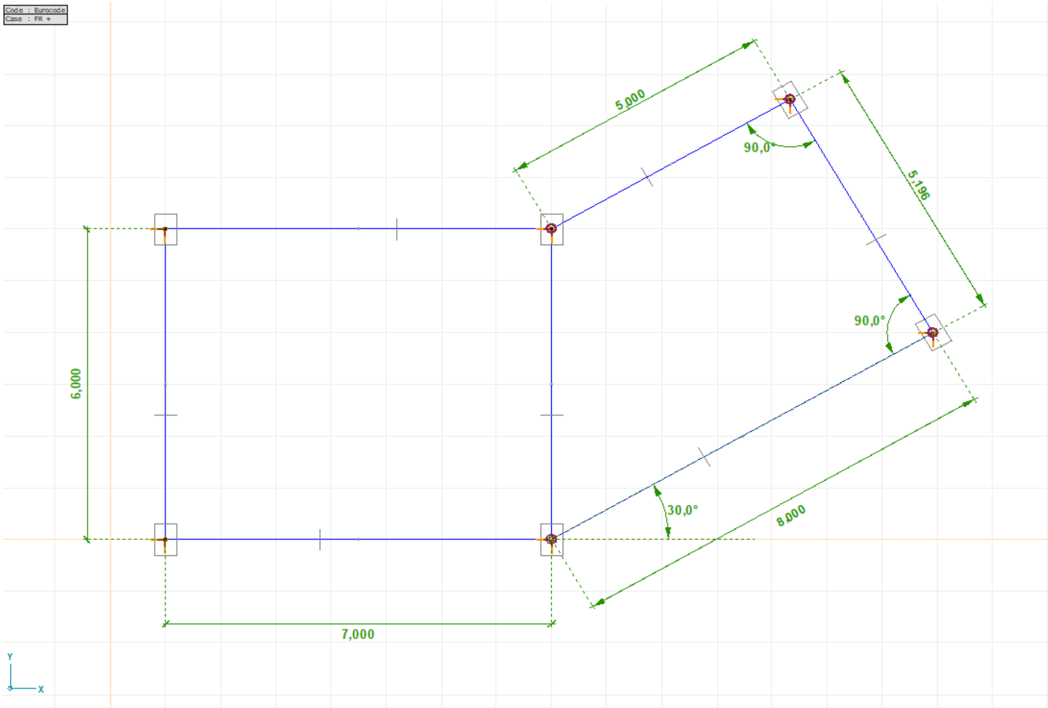
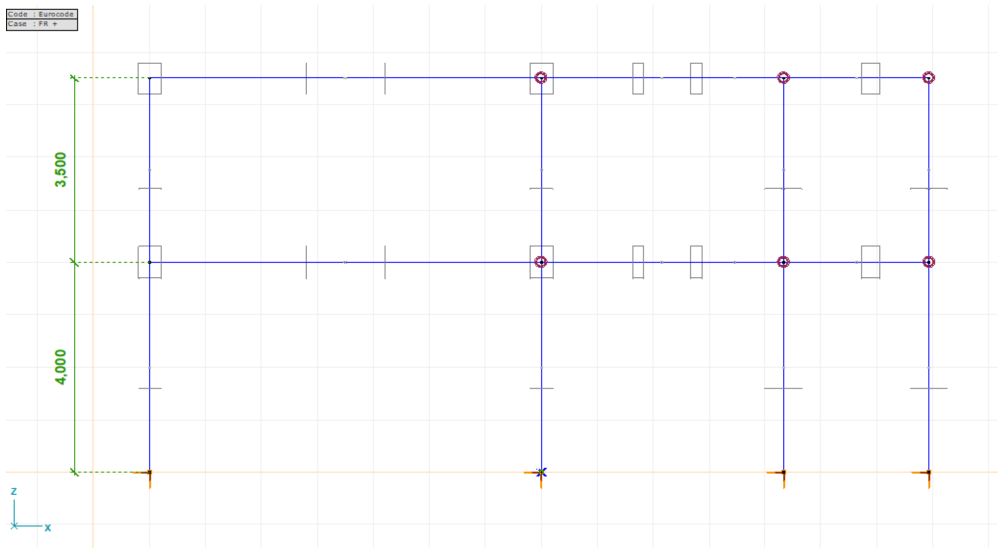
Software Release Number: X5r1
Date: 19. 11. 2018.
Tested by: InterCAD
Reference: Eurocodes: Background & Applications Structural Fire Design
File name: timber_fire_2.axs

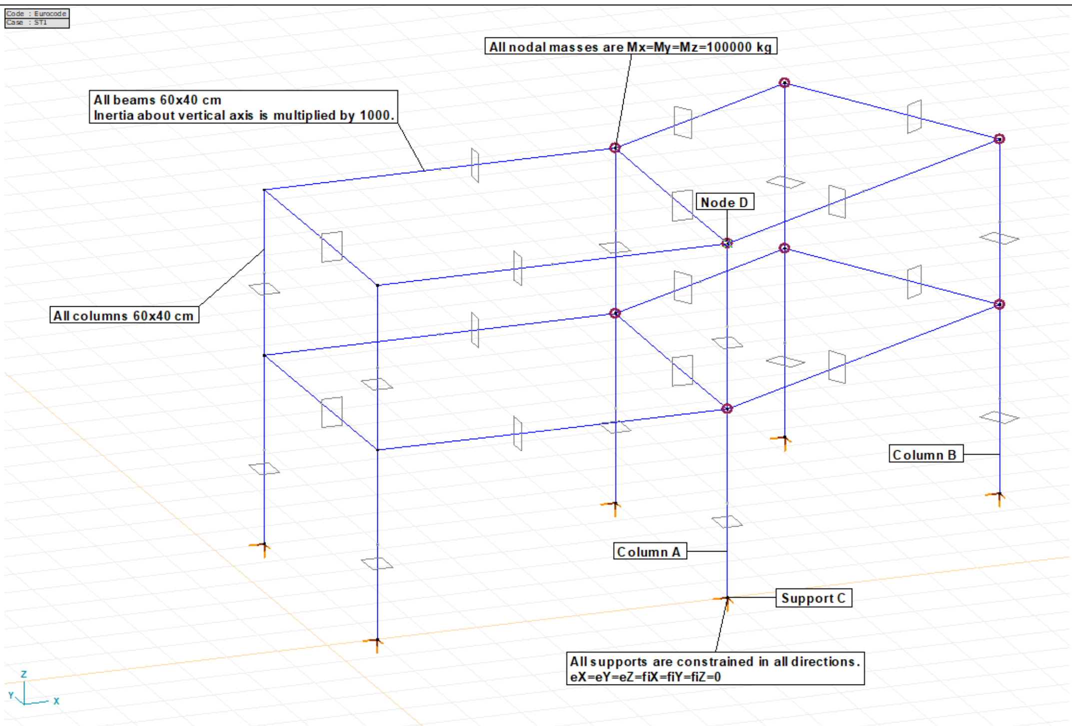
Thema	Fire design of timber elements – Protected column (EN 1995-1-2)
Analysis Type	Timber Design
Geometry	 
Loads	Concentrated load on the top: $N_{d,fi}$ = 59 kN R60 required fire resistance; protection: 18 mm gypsum board, $t_a = t_{ch}$ = 36 min
Boundary Conditions	eX = eY = eZ = fiZ = 0 at the bottom eX = eY = 0 at the top
Material Properties	C24 E = 1100 kN / cm^2 ν = 0,2
Element types	Beam element

Results

	Analytical solution	AxisVM	e [%]
d_{ef} [mm]	38.8	38.8	0.0
$k_{c,fi}$ [-]	0.2	0.2	0.0
η [-]	1.64	1.66	+1.0

Software Release Number: X5r1
Date: 07. 11. 2018.
Tested by: InterCAD
File name: Earthquake-01-EC.axs

Thema	Earth-quake design using response-spectrum method.
Analysis Type	Linear frequency analysis with 5 modes. Linear static analysis.
Geometry	 Top view  Front view



Perspective view

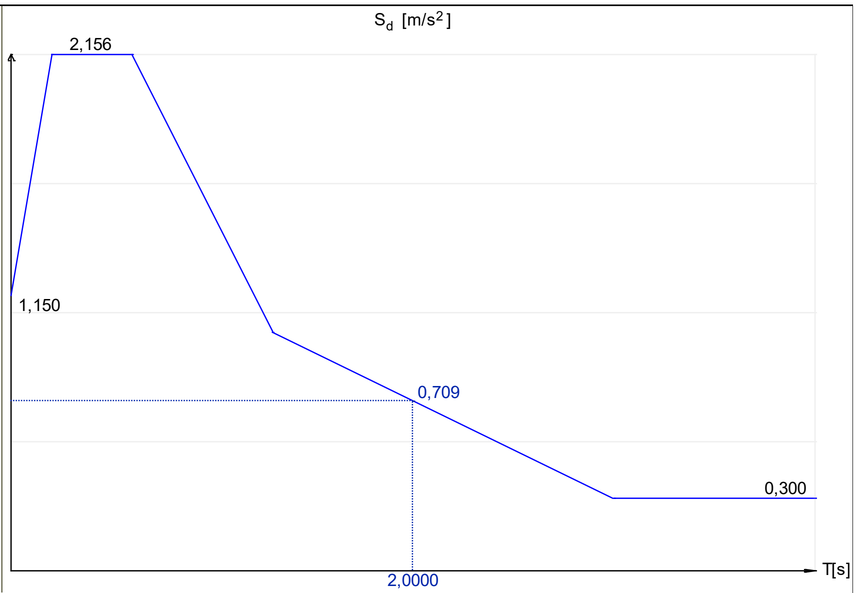
Section beams: 60x40 cm
Ax=2400 cm2 Ay=2000 cm2 Az=2000 cm2
Ix=751200 cm4 Iy=720000 cm2 Iz=320000000 cm4

Section columns: 60x40 cm
Ax=2400 cm2 Ay=2000 cm2 Az=2000 cm2
Ix=751200 cm4 Iy=720000 cm2 Iz=320000 cm4

Loads

Nodal masses on eight nodes. Mx=My=Mz=100000 kg
Model self-weight is excluded.
q_d = 1
Spectrum for X and Y direction of seismic action:

	T[s]	S_d
1	0	1,150
2	0,2000	2,156
3	0,6000	2,156
4	1,3000	0,995
5	3,0000	0,300
6	4,0000	0,300
	. . .	. . .



Boundary Conditions

Nodes at the columns bottom ends are constrained in all directions.
eX=eY=eZ=fiX=fiY=fiZ=0

Material Properties

C25/30
E=3050 kN/cm2 ν =0,2 ρ = 0

Element types	Rib element: Three node straight prismatic beam element. Shear deformation is taken into account.
Target	Compare the model results with SAP2000 v6.13 results. The results are combined for all modes and all direction of spectral acceleration. CQC combination are used for modes in each direction of acceleration. SRSS combination are used for combination of directions.
Results	(see below)

Period times of first 5 modes

Mode	T[s] SAP2000	T[s] AxisVM	Difference [%]
1	0,7450	0,7450	0
2	0,7099	0,7098	+0,01
3	0,3601	0,3601	0
4	0,2314	0,2314	0
5	0,2054	0,2053	+0,05

Modal participating mass ratios in X and Y directions

Mode	εX SAP2000	εX AxisVM	Difference %	εY SAP2000	εY AxisVM	Difference %
1	0,5719	0,5723	+0,07	0,3153	0,3151	-0,06
2	0,3650	0,3647	-0,08	0,4761	0,4764	+0,06
3	0	0	0	0,1261	0,1261	0
4	0,0460	0,0461	+0,22	0,0131	0,0131	0
5	0,0170	0,0170	0	0,0562	0,0561	0
Summ	**1,0000**	**1,0000**	**0**	**0,9868**	**0,9868**	**0**

Internal forces at the bottom end of Column A and Column B

	Column A SAP2000	Column A AxisVM	Difference %	Column B SAP2000	Column B AxisVM	Difference %
Nx [kN]	315,11	315,15	-0,013	557,26	557,29	-0,005
Vy [kN]	280,34	280,34	0	232,88	232,88	0
Vz [kN]	253,49	253,49	0	412,04	412,04	0
Tx [kNm]	34,42	34,41	-0,032	34,47	34,46	-0,029
My [kNm]	625,13	625,12	-0,002	1038,74	1038,73	-0,001
Mz [kNm]	612,31	612,31	0	553,41	553,41	0

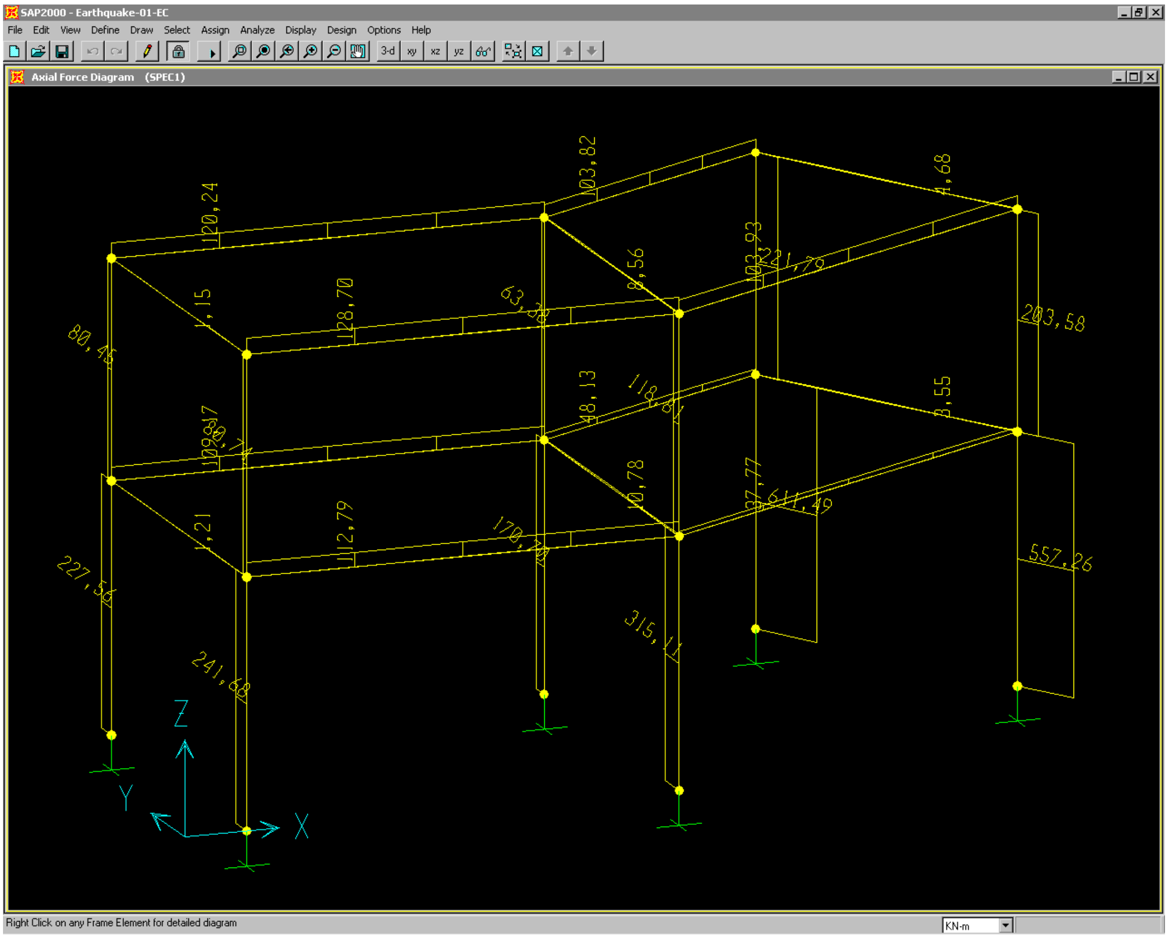
Support forces of Support C

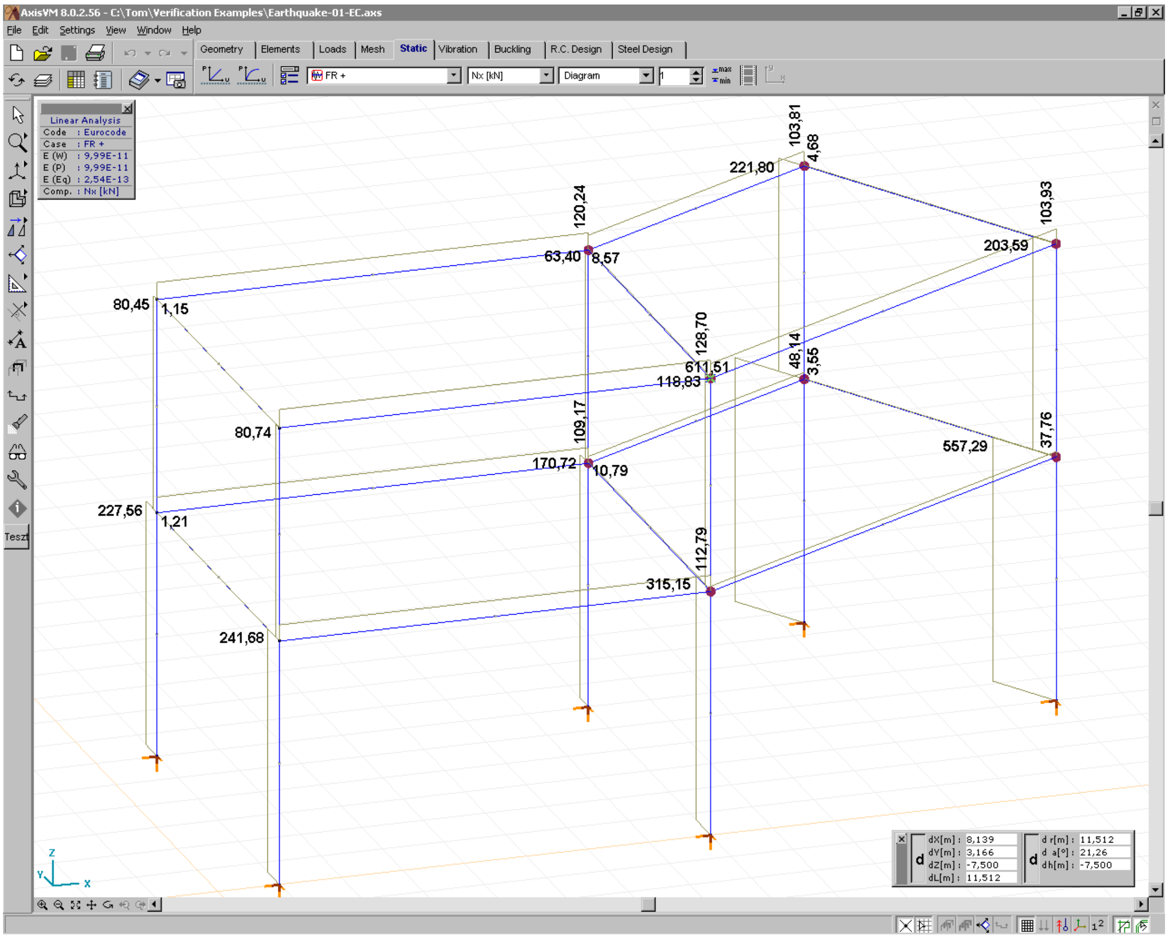
	Support C SAP2000	Support C AxisVM	Difference %
Rx [kN]	280,34	280,34	0
Ry [kN]	253,49	253,49	0
Rz [kN]	315,11	315,15	-0,013
Rxx [kNm]	625,13	625,12	-0,002
Ryy [kNm]	612,31	612,31	0
Rzz [kNm]	34,42	34,41	+0,029

Displacements of Node D

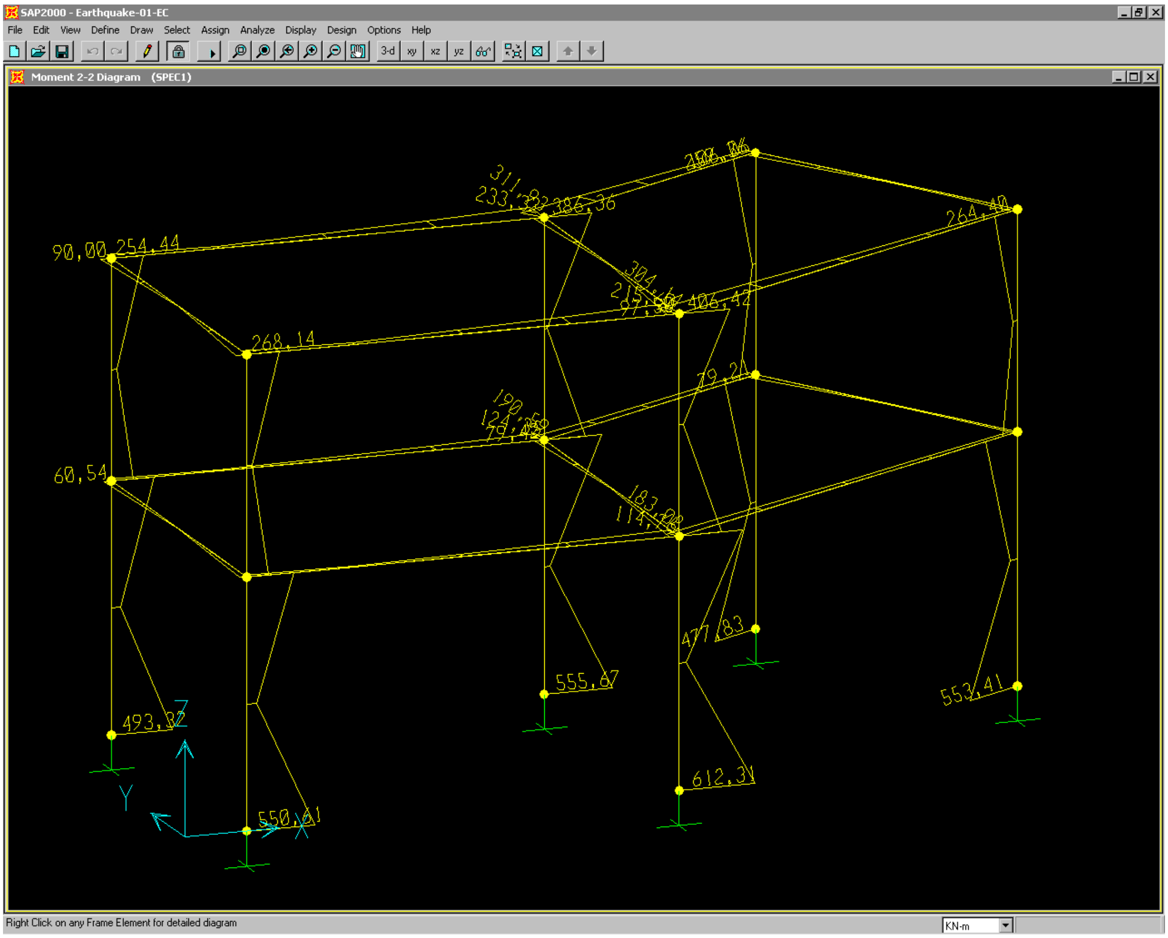
	Node D SAP2000	Node D AxisVM	Difference %
eX [mm]	33,521	33,521	0
eY [mm]	19,944	19,945	-0,005
eZ [mm]	0,229	0,229	0
φX [rad]	0,00133	0,00133	0
φY [rad]	0,00106	0,00106	0
φZ [rad]	0,00257	0,00257	0

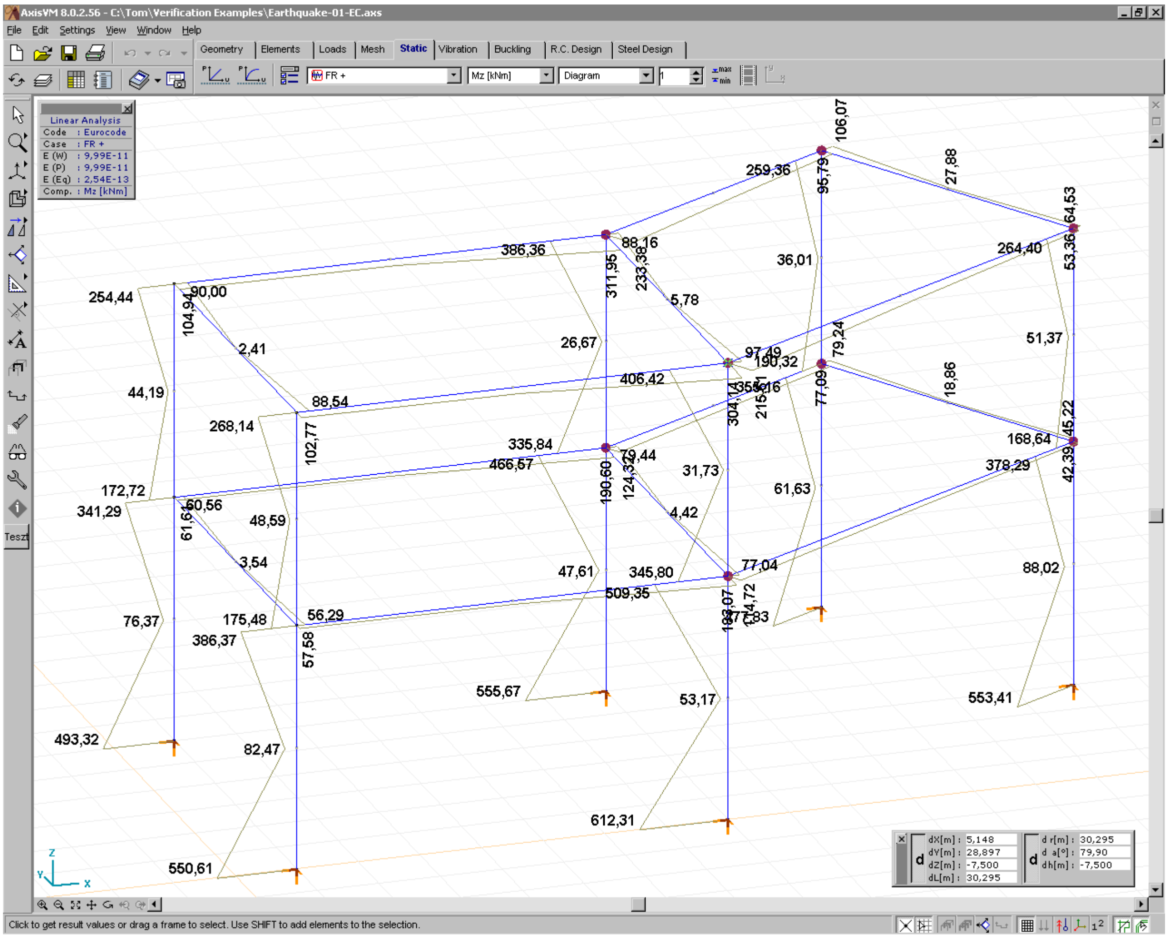
Normal forces:

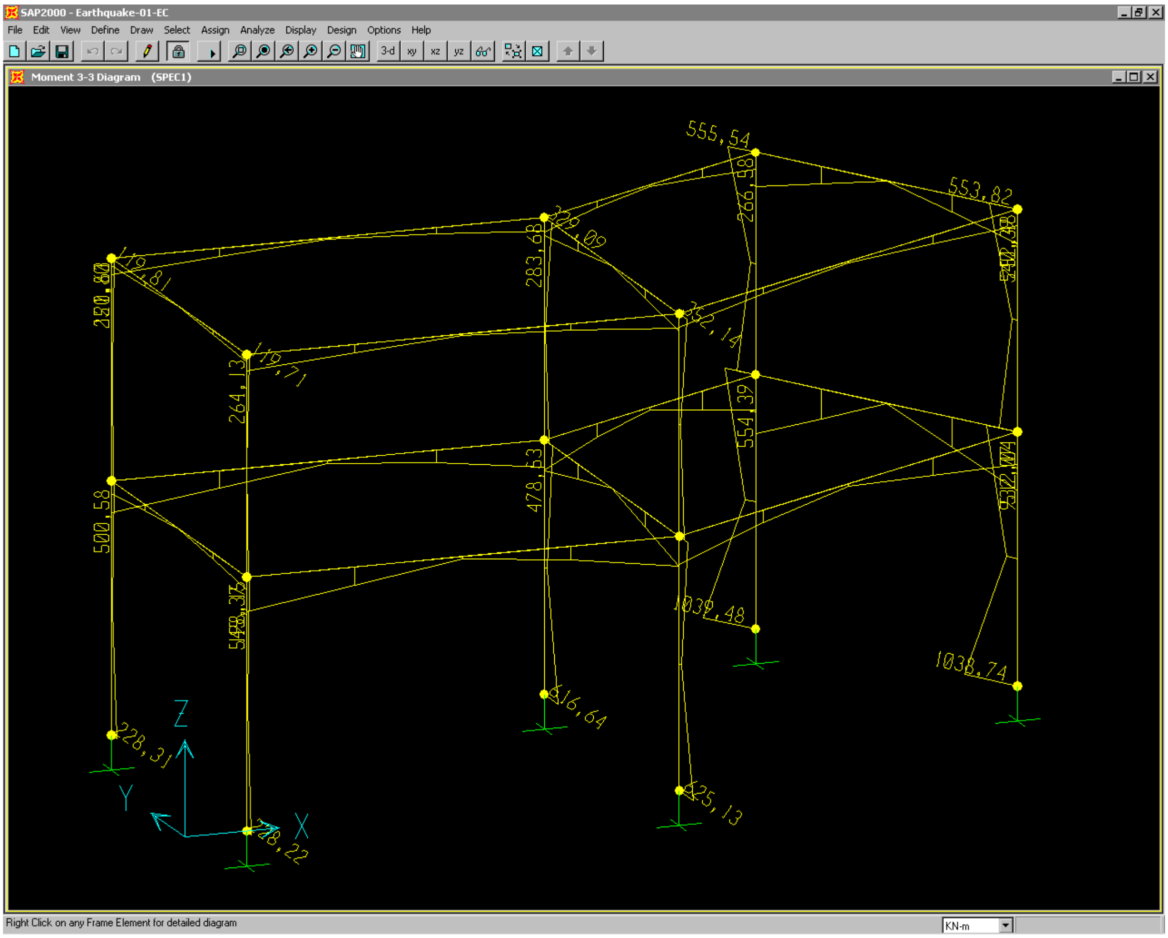


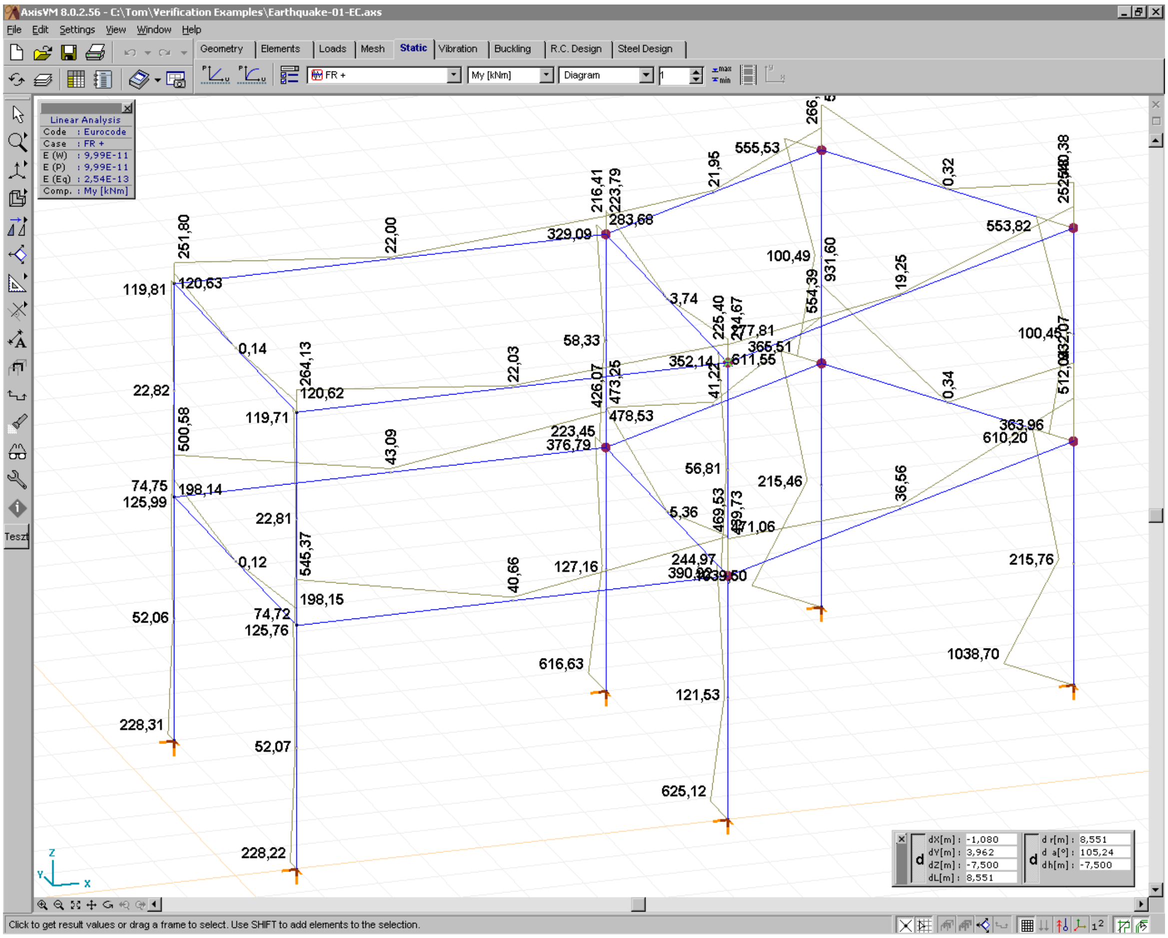


Bending moments:

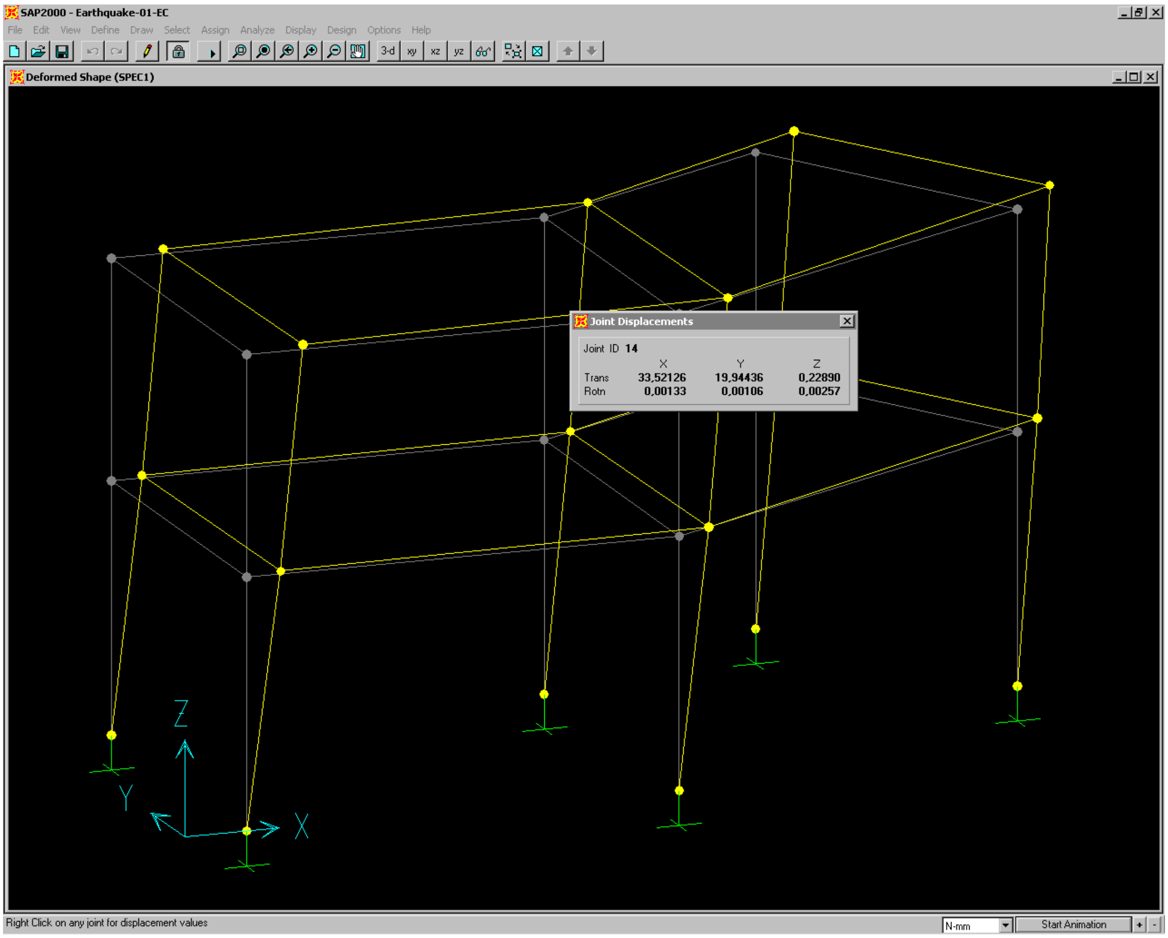


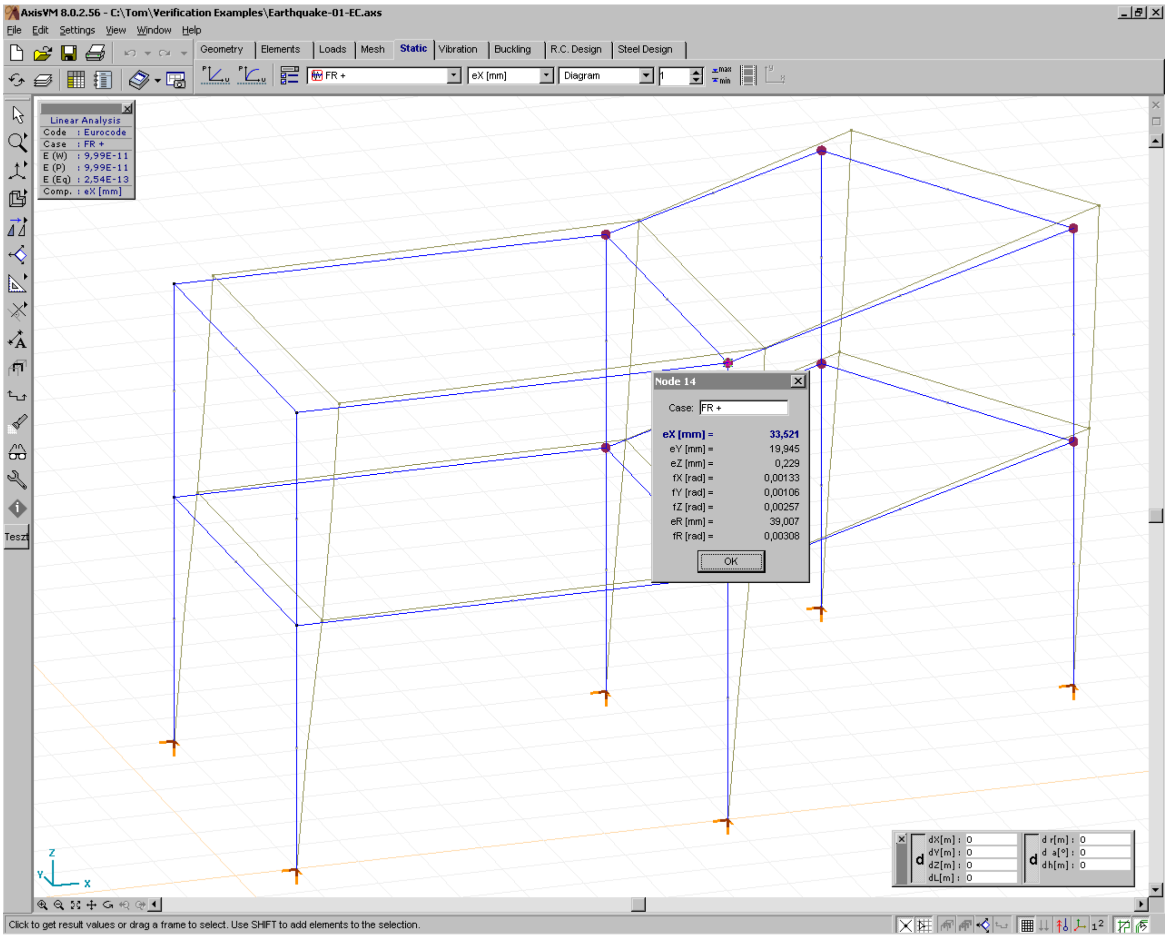



SAP2000 - Earthquake-01-EC
File Edit View Define Draw Select Assign Analyze Display Design Options Help
Moment 3-3 Diagram (SPEC1)
555,54
553,82
283,68
500,58
1039,48
1038,74
616,64
625,13
228,31
228,22
Right Click on any Frame Element for detailed diagram
KN-m

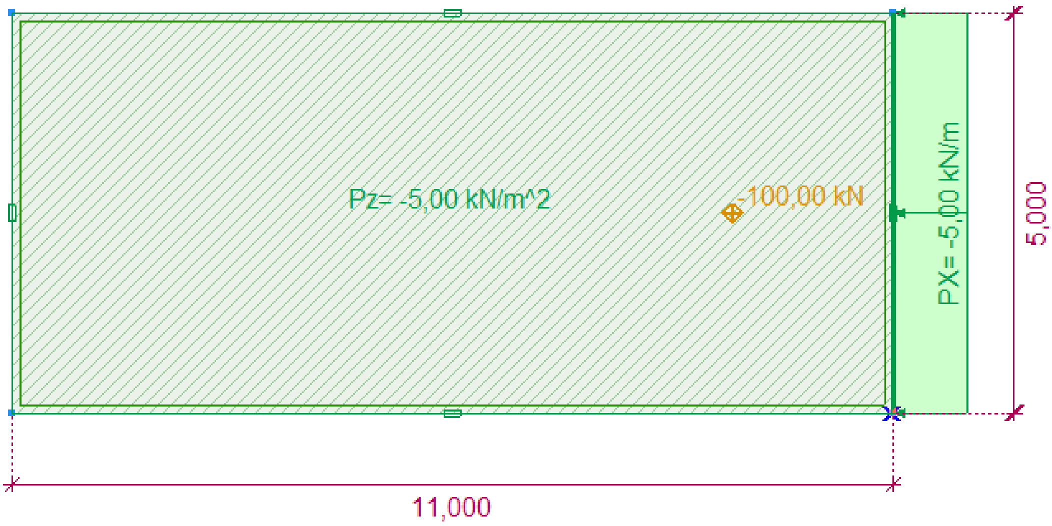
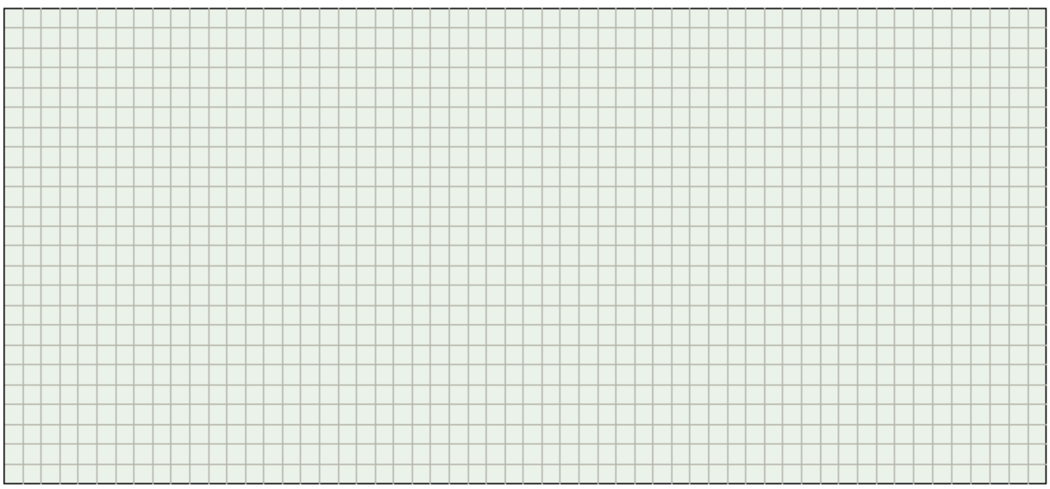

AxisVM 8.0.2.56 - C:\Tom\Verification Examples\Earthquake-01-EC.axs
File Edit Settings View Window Help
Geometry Elements Loads Mesh Static Vibration Buckling R.C. Design Steel Design
FR +
My [kNm]
Diagram
Linear Analysis
Code : Eurocode
Case : FR +
Comp. : My [kNm]
dX[m] : -1,080
dY[m] : 3,962
dZ[m] : -7,500
dL[m] : 8,551
d r[m] : 8,551
d a[°] : 105,24
dh[m] : -7,500
Click to get result values or drag a frame to select. Use SHIFT to add elements to the selection.

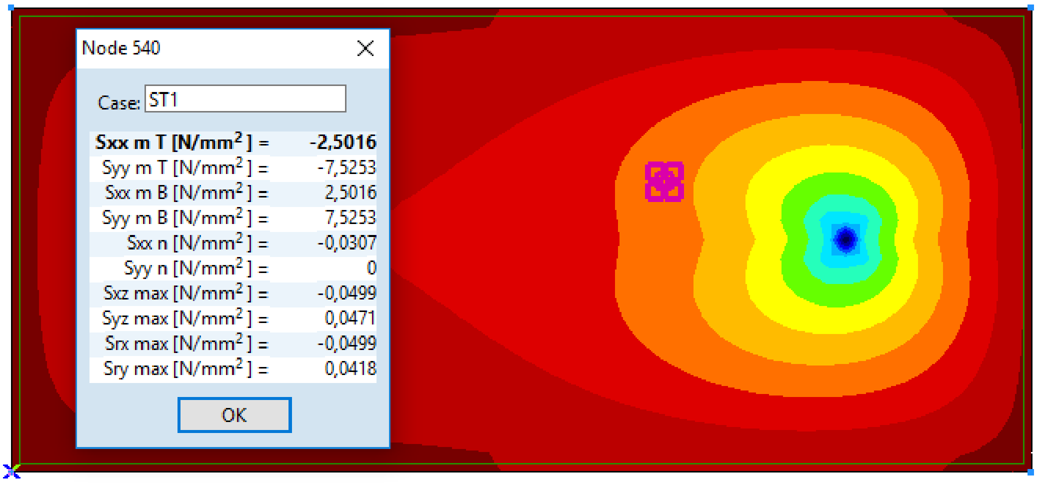
Displacements:



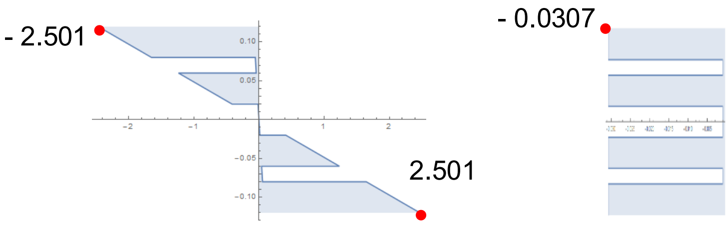


Software Release Number: X5r1
Date: 09. 11. 2018.
Tested by: InterCAD
File name: XLAM_Example_2.axs

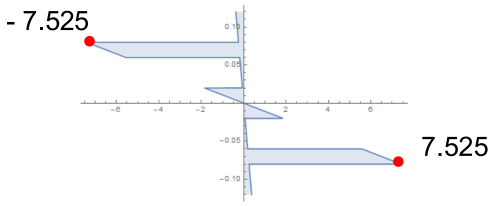
Thema	Design of an XLAM shell (EC5).
Analysis Type	Linear analysis.
Geometry	 Top view (x-y plane)
Loads	P = -100 kN concentrated force acting at point (x = 9.0 m, y = 2.5 m) Pz = -5.00 kN/m^2 uniform load PX = -5.00 kN/m line load on the right edge
Boundary Conditions	eZ =0 along all edges eX = 0 along the left edge eY = 0 along the top edge The remaining DOFs are left free.
Material Properties	Material quality equals to C24 timber.
Section Properties	MM 7s/240 XLAM section with “x” oriented top layer grain direction and Service Class 2, producing an overall thickness of 240 mm.
Element types	Shell element (Parabolic quadrilateral, heterosis type)
Mesh	 Average element length is 0.2 m.
Target	Efficiency at node 540 (x = 7.043 m, y = 3.125 m).
	Stresses calculated with Axis VM



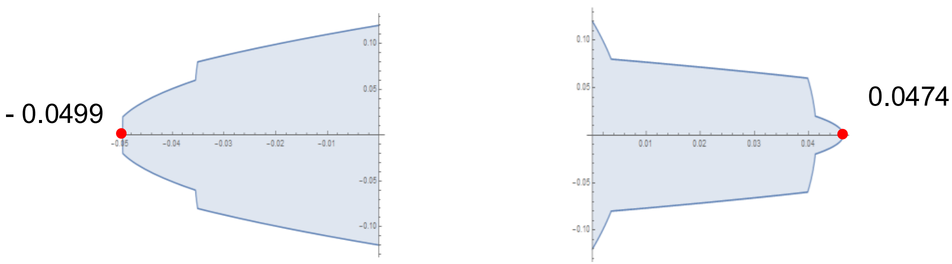
Normal stresses in x direction from bending and normal forces [N/mm^2]



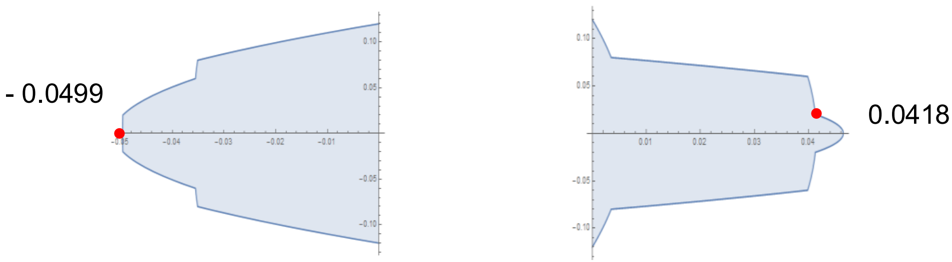
Normal stresses in y direction from bending [N/mm^2]



Shear stresses in x and y direction [N/mm^2]



Rolling shear stresses in x and y direction [N/mm^2]



Design value of strength [N/mm^2]

	Service Class : 2 Load-duration class : permanent k_{mod} = 0.6

System strength factor[1] : k_{sys} = Min(1.2, 1+0.025*7) = 1.175
Partial safety factor of the material : γ_M = 1.3

$$f_{m,d} = k_{sys}\frac{k_{\text{mod}} \cdot f_{m,k}}{\gamma_M} = 13015.38 \cdot 10^{-3}$$

$$f_{v,d} = \frac{k_{\text{mod}} \cdot f_{v,k}}{\gamma_M} = 1846.15 \cdot 10^{-3}$$

$$f_{t,0,d} = k_{sys}\frac{k_{\text{mod}} \cdot f_{t,0,k}}{\gamma_M} = 7592.31 \cdot 10^{-3}$$

$$f_{t,90,d} = k_{sys}\frac{k_{\text{mod}} \cdot f_{t,90,k}}{\gamma_M} = 216.92 \cdot 10^{-3}$$

$$f_{c,0,d} = \frac{k_{\text{mod}} \cdot f_{c,0,k}}{\gamma_M} = 9692.31 \cdot 10^{-3}$$

$$f_{c,90,d} = \frac{k_{\text{mod}} \cdot f_{c,90,k}}{\gamma_M} = 1153.85 \cdot 10^{-3}$$

$$f_{r,d} = \frac{k_{\text{mod}} \cdot f_{r,k}}{\gamma_M} = 461.54 \cdot 10^{-3}$$

M-N efficiency (hand calculation)

$$\left|\frac{\sigma_{mx,\max,d}}{f_{m,d}}\right| + \left|\frac{\sigma_{cx,\max,d}}{f_{t,d}}\right| = \left|\frac{-2.501}{13015.38 \cdot 10^{-3}}\right| + \left|\frac{-0.0307}{9692.31 \cdot 10^{-3}}\right| = 0.1952$$

$$\left|\frac{\sigma_{my,\max,d}}{f_{m,d}}\right| = \left|\frac{-7.525}{13015.38 \cdot 10^{-3}}\right| = 0.5782$$

Max(0.1952, 0.5782) = **0.5782**

Shear efficiency (hand calculation)

$$\left|\frac{\tau_{xz,\max,d}}{f_{v,d}}\right| = \left|\frac{-0.049}{1846.15 \cdot 10^{-3}}\right| = 0.02654$$

$$\left|\frac{\tau_{yz,\max,d}}{f_{v,d}}\right| = \left|\frac{0.047}{1846.15 \cdot 10^{-3}}\right| = 0.02545$$

Max(0.02654, 0.02545) = **0.02654**

[1] : k_{sys} = Min(1.1, 1+0.025*n) if NTC design code is selected

Rolling shear efficiency (hand calculation)

$$\left|\frac{\tau_{rx,\max,d}}{f_{r,d}}\right| = \left|\frac{-0.0499}{461.54 \cdot 10^{-3}}\right| = 0.1081$$

$$\left|\frac{\tau_{ry,\max,d}}{f_{r,d}}\right| = \left|\frac{0.0418}{461.54 \cdot 10^{-3}}\right| = 0.09057$$

Max(0.1081, 0.09057) = **0.1081**

Maximum efficiency from hand calculations

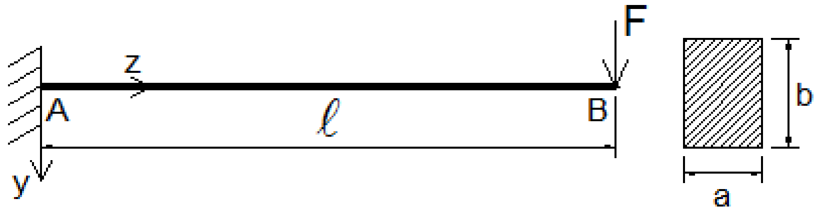
Max(0.5782, 0.02654, 0. 1081) = **0.5782**

Efficiency calculated with Axis VM compared to the results from the previous hand calculations

x	y	Description	AxisVM	hand calculations	Diff [%]
7.043 m	3.125 m	M-N efficiency	**0.578**	0.578	0.00
7.043 m	3.125 m	Shear efficiency	**0.027**	0.027	0.00
7.043 m	3.125 m	Rolling shear efficiency	**0.108**	0.108	0.00
7.043 m	3.125 m	Maximum efficiency	**0.578**	0.578	0.00

Appendix A

Date: 07. 02. 2018.
Tested by: InterCAD

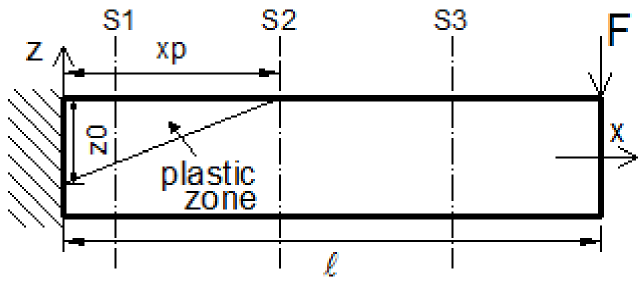
Thema	Clamped beam with *symmetrical nonlinear* material model – Theoretical background
Geometry	
References	S. Kaliszky Mechanika II. Tankönyvkiadó, Budapest, 1990
Equations	Material function: $$\sigma = C \cdot \varepsilon^n \quad (1)$$ Moment of inertia: $$J_{n+1} = a \int_{-b/2}^{b/2} y^{n+1} dy \quad (2)$$ Second-order linear differential equation for elastic curve: $$\frac{d^2v}{dz^2} = -\left(\frac{M}{CJ_{n+1}}\right)^{1/n} \quad (3)$$ Bending moment: $$M(z) = F(l-z) \quad (4)$$ Boundary conditions: $$z = 0, \frac{dy}{dz} = 0; \quad (5)$$ $$z = 0;\ y = 0 \quad (6)$$ Deflection equation based on previous equations ($n = 1/2$): $$y = \frac{F^2\left(\frac{l^2z^2}{2} - \frac{lz^3}{6} + \frac{z^4}{12}\right)}{(CJ_{n+1})^{1/n}} \quad (7)$$

Software Release Number: X4r3
Date: 07. 02. 2018.
Tested by: InterCAD

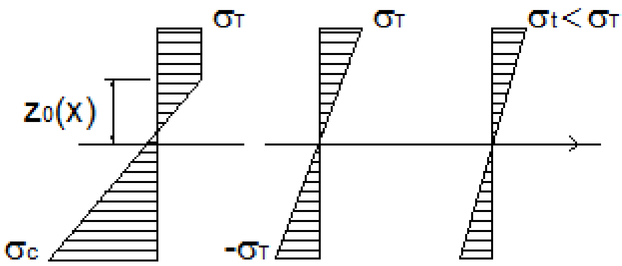
Thema

Clamped beam with *asymmetrical nonlinear* material model – Theoretical background

Geometry



Stress distribution



Equations

In the nonlinear zone (S1 section)

$$\sigma(x,z)=\begin{cases}\sigma_T & \text{if } z_0(x)<z\\ \sigma_T-E\kappa(x)\big(z-z_0(x)\big) & \text{if } z<z_0(x)\end{cases} \qquad (1)$$

The normal force and the moment equations of equilibrium are given by

$$0=\sigma_T hv-\int_{-\frac{h}{2}}^{z_0} E\kappa(x)\big(z-z_0(x)\big)vdz \qquad (2)$$

$$F(\ell-x)=-\int_{-\frac{h}{2}}^{z_0} E\kappa(x)(z-z_0)vzdz \qquad (3)$$

Solving equations (2) and (3) the nonlinear cross-section and the curvature is obtained by

$$z_0(x)=h-3\frac{F(\ell-x)}{\sigma_T hv} \qquad (4)$$

$$\kappa(x)=\frac{2\sigma_T h}{9E\left[\frac{h}{2}-\frac{2F}{\sigma_T hv}(\ell-x)\right]^2} \qquad (5)$$

The length of the nonlinear zone is obtained from equation (4) under the condition

$$z_0(x_P)=\frac{h}{2}$$

$$x_P=\ell-\frac{\sigma_T h^2 v}{6F} \qquad (6)$$

The nonlinear zone of the supported cross-section is also obtained from equation (4)

$$z_0(0)=h-3\frac{F\ell}{\sigma_T hv} \qquad (7)$$

Substituting equation (4) and (5) to equation (1) under the conditions $x_c=20\ \text{cm}$ and z= $-\frac{h}{2}$ the maximal compressive stress at the supported end is obtained by:

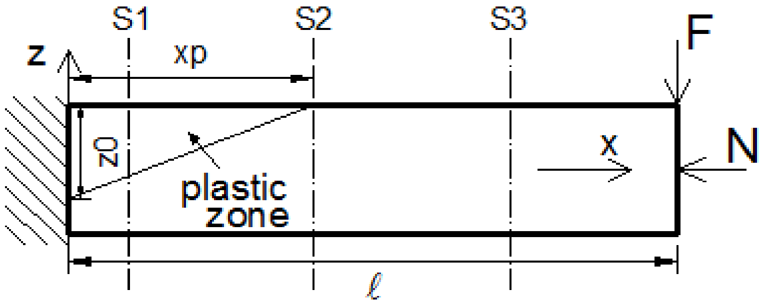
$$\sigma\left(x_c,-\frac{h}{2}\right)=-E\kappa(x_c)\left(-\frac{h}{2}-z_0(x_c)\right) \qquad (8)$$

	In the linear zone (S3 section)
	The stress distribution is given by $$\sigma(x,z) = -E\kappa(x)z \quad (9)$$ The moment equation of equilibrium is given by $$F(\ell - x) = -\int_{-\frac{h}{2}}^{z_0} E\kappa(x)zvzdz \quad (9)$$ Solving equation (10) the curvature is obtained by $$\kappa(x) = \frac{12F(\ell - x)}{Eh^3v} \quad (11)$$ Integrating equations (5) and (11) two times the deflection is obtained by $$e_z(l) = \int_0^{\ell}\int_0^{x} \kappa(\xi)d\xi\, dx \quad (12)$$

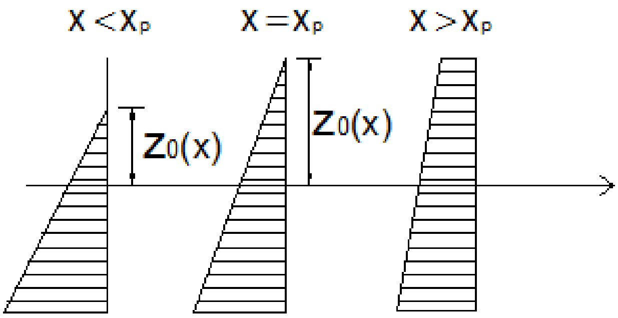
Software Release Number: X4r3
Date: 07. 02. 2018.
Tested by: InterCAD

Thema	Clamped beam with *only compression nonlinear* material model – Theoretical background

Geometry



Stress distribution



Equations

In the nonlinear zone (S1 section)

$$\sigma(x,z) = \begin{cases} 0 & \text{if } \; z_0(x) < z \\ -E\kappa(x)\big(z - z_0(x)\big) & \text{if } \; z < z_0(x) \end{cases} \qquad (1)$$

The normal force and the moment equations of equilibrium are given by

$$N = \int_{-\frac{h}{2}}^{z_0} E\kappa(x)\big(z - z_0(x)\big)v\,dz \qquad (2)$$

$$F(\ell - x) = -\int_{-\frac{h}{2}}^{z_0} E\kappa(x)(z - z_0)vz\,dz \qquad (3)$$

Solving equations (2) and (3) the nonlinear cross-section and the curvature is obtained by

$$z_0(x) = h - 3\frac{F(\ell - x)}{N} \qquad (4)$$

$$\kappa(x) = \frac{8N^3}{9Ev[Nh - 2F(\ell - x)]^2} \qquad (5)$$

The length of the nonlinear zone is obtained from equation (4) under the condition

$$z_0(x_P) = \frac{h}{2}$$

$$x_P = \ell - \frac{Nh}{6F} \qquad (6)$$

The nonlinear zone of the supported cross-section is also obtained from equation (4)

$$z_0(0) = h - 3\frac{F\ell}{N} \qquad (7)$$

Substituting equation (4) and (5) to equation (1) under the conditions $x_c = 20\,\text{cm}$ and $z = -\frac{h}{2}$ the maximal compressive stress at the supported end is obtained by:

$$\sigma\left(x_c, -\frac{h}{2}\right) = -E\kappa(x_c)\left(-\frac{h}{2} - z_0(x_c)\right) \qquad (8)$$

	In the linear zone (S3 section)
	The stress distribution is given by $$\sigma(x,z) = -E\kappa(x)z \quad (9)$$ The moment equation of equilibrium is given by $$F(\ell - x) = -\int_{-\frac{h}{2}}^{z_0} E\kappa(x)zvzdz \quad (10)$$ Solving equation (9) the curvature is obtained by $$\kappa(x) = \frac{12F(\ell - x)}{Eh^3v} \quad (11)$$ Integrating equations (5) and (10) two times the deflection is obtained by $$e_z(l) = \int_0^{\ell}\int_0^{x} \kappa(\xi)d\xi\, dx \quad (12)$$